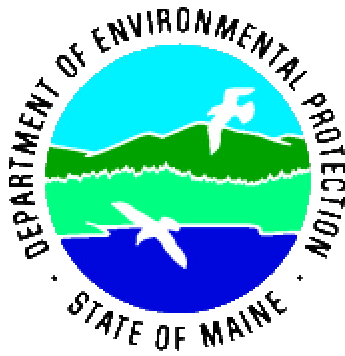


Sabattus River Modeling Report

January 2004

DEPLW0624



**Prepared by David Miller, P.E.
Bureau of Land and Water Quality
Division of Environmental Assessment**

Executive Summary

The Sabattus River is included on Maine's list (section 303d, clean water act, category 5-A) for non-attainment of water quality standards, requiring a TMDL (total maximum daily load assessment). During August 2000 and August 2002 water quality surveys were performed to collect data for a water quality model. This model is to be used to evaluate alternatives as part of the TMDL.

A water quality model was developed for the Sabattus River. Modeling indicates non-attainment of dissolved oxygen (DO) standards at critical low streamflow conditions. The cause of the non-attainment is chiefly historic organic loading (from Sabattus Pond) in combination with hydraulic alteration caused by dams on the river. The permitted discharges also have small but not insignificant impacts upon instream DO due mainly to phosphorous loading resulting in algae growth.

A number of modeling scenarios was investigated. In general non-attainment of DO standards is significantly reduced in terms of river miles under a scenario of increased river flow and performance loading from the permitted dischargers. No scenario results in 100% attainment with the existing dams in place or without a significant reduction in sediment oxygen demand (SOD).

Under 7Q10 low flow conditions and permit loading 63% of the river experiences algae bloom conditions (chl-a > 8 ug/l). Under 30Q10 (monthly average) low flow conditions 100% of the river experiences algae bloom conditions. There are currently no numeric algae bloom standards for rivers but nutrient criteria standards are under development and expected to be implemented by 2005.

Table of Contents

Executive Summary	i
Introduction.....	1
Summary of Survey Data	1
Water Quality Model.....	2
Model Transport.....	2
Model Parameters and Rates.....	4
Reaeration Coefficient.....	4
Chemical Calibration.....	4
Dissolved Oxygen.....	6
CBOD.....	8
Phytoplankton (chl-a).....	9
Nutrients.....	10
Sensitivity Analysis.....	12
7Q10 Predictive Model.....	13
Runs With Predictive Model.....	13
7Q10.....	13
7Q10 with Diurnal.....	14
Component Analysis	16
Monthly Average Flow	18
Performance	19
Modeling Scenarios.....	21
7Q10 Runs	21
30Q10 Runs	22
Discussion.....	23
APPENDIX	25

Tables

Table 1 Hydraulic Coefficients.....	3
Table 2 2002 Transect Data	4
Table 3 Model Parameters/Rates.....	5
Table 4 Reach Variable Parameters/Rates.....	6
Table 5 Daily Average Dissolved Oxygen Sensitivity, DO change, mg/l.....	12
Table 6 Daily Average Dissolved Oxygen Sensitivity Range**, mg/l.....	12
Table 7 SOD in Maine Rivers.....	12
Table 8 Point Source Permit Loads for Model Input	13
Table 9 Point Source Performance Loads (5 year average).....	19
Table 10 Model Scenarios.....	21

Figures

Figure 1 Sabattus Model Daily Average DO, 2002 Survey.....	7
Figure 2 Sabattus Model Daily Average DO, 2000 Survey.....	7
Figure 3 Sabattus Model CBOD, 2002 Survey.....	8
Figure 4 Sabattus Model CBOD, 2000 Survey.....	8
Figure 5 Sabattus Model chl-a, 2002 Survey.....	9
Figure 6 Sabattus Model chl-a, 2000 Survey.....	9
Figure 7 Sabattus Model TP, 2002 Survey	10
Figure 8 Sabattus Model TN, 2002 Survey.....	10
Figure 9 Sabattus Model TP 2000 Survey.....	11
Figure 10 Sabattus Model TN, 2000 Survey.....	11
Figure 11 Sabattus Daily Average DO, 7Q10 Simulation, Permit Loads.....	14
Figure 12 Diurnal DO vs chl-a, 2002 data	15
Figure 13 Sabattus Diurnal DO, 7Q10 Simulation, Permit Loads.....	15
Figure 14 DO Depletion Analysis Rivermile -0.66	16
Figure 15 DO Depletion Analysis Rivermile -4.38	17
Figure 16 DO Depletion Analysis Rivermile -7.25	17
Figure 17 Phosphorous Loading-Average Resulting Increase in Chl-a.....	18
Figure 18 Sabattus Monthly Average DO, License Limit Simulation.....	19
Figure 19 Sabattus Diurnal DO, 7Q10 Simulation, Performance Loading.....	20
Figure 20 Sabattus Monthly Average Dissolved Oxygen, Performance Loads.....	20
Figure 21 Minimum DO for Selected Critical Flow Scenarios.....	22
Figure 22 DO for Monthly Average Scenarios	23

Introduction

The Sabattus River (class C to below Lisbon) forms the outlet of Sabattus Pond and extends approximately 10 miles to the Androscoggin River. The town of Sabattus discharges treated wastewater (0.12 MGD) to the Sabattus River approximately 0.9 mile below the pond. A small OBD¹ (MEU501622, 0.02 MGD) is located about 0.4 mile below Crowley Road Bridge. Maine Electronics (0.079 MGD) discharges treated groundwater to the Sabattus River in Lisbon. River flow is regulated at the outlet dam (minimum flow 2.5 cfs).

Sabattus Pond experiences algae blooms most years and is on the state's 303d list for non-attainment of water quality standards requiring a TMDL (total maximum daily load analysis) with studies currently underway. Charts showing the results of pond sampling for total phosphorous and chl-a² are included in the appendix (p. A1). Five dams are located on the river including the pond outlet dam. A map showing the locations of the dams and the licensed discharges is included in the appendix (p. A2). Water withdrawals for irrigation reduce river flows. All these factors may contribute to instream DO (dissolved oxygen) problems. During 1994, non-attainment of DO standards was measured at two sites on the river. The Sabattus River is also on the state's 303d TMDL list, category 5-A for non-attainment of water quality standards (listed for DO and nutrient loading). A water quality study was initiated during the summer of 2000 with the completion of a three day intensive survey (see Sabattus River Data Report August 2000 Survey, November 2001, #DEPLW0446). An additional three day survey was completed in 2002 (see Sabattus River Data Report August 2002 Survey, April 2003, #DEPLW0591).

This report discusses the water quality model development for the Sabattus River. The model focuses on the segment between Sabattus Pond (actually the first bridge below the outlet dam) and Lisbon Center (dam at Mill Street), a distance of approximately 9 miles. The drainage area of the Sabattus River at the outlet of Sabattus Pond is 33.8 mi.² and at the confluence of the Androscoggin River is 73.8 mi.². The modeled river segment is classified C, requiring among other standards, a minimum DO concentration of 5 ppm or 60% saturation, whichever is greater and a monthly average of 6.5 ppm. Below the Lisbon urban area (Mill Street) the river is classified B, requiring a minimum DO concentration of 7 ppm or 75% saturation.

Summary of Survey Data

The quality of the 2000 and 2002 data is considered adequate due to sufficient QC (quality control) measures utilized throughout the sampling efforts that included such practices as cross checking of dissolved oxygen meters and duplicate sampling. It did become apparent through the model calibration process that the ambient CBOD³ data were affected by the elevated chl-a concentrations. The respiring algae added to the utilization of DO in the lab bottles (see the section on Chemical Calibration-CBOD).

No significant runoff events occurred during either survey and the streamflow remained steady during the sampling. The minimum designated flow at the outlet dam is 2.5 cfs. Streamflow during the 2000 survey was almost double that during the 2002 survey (10.3 vs. 6 cfs at the Rt. 126 bridge). Although it is desirable to have different flows for the two datasets, the higher 2000 flow is considered marginally

¹ overboard discharge

² chlorophyll-a, a measure of algae mass

³ long term carbonaceous biochemical oxygen demand

acceptable in terms of a low flow model calibration. Therefore the 2002 dataset was used for initial model setup and calibration with the 2000 dataset used for verification. Also, more weight in terms of the model calibration was placed on the 2002 data. The 2002 survey was conducted in the middle of an extended drought condition so that the natural base flows (i.e., uncontrolled, dry weather flows) probably represent critical conditions. Therefore the tributary and incremental inflows measured/calculated during the 2002 survey were used directly in the low flow prediction model.

Sabattus Pond exhibited improved water quality conditions (in terms of algae) at the outlet during 2002 when compared to 2000. This can be seen in the background chl-a data from each survey. The initial algae loading was greater during 2000 but algae growth in the stream itself was greater during 2002. Again it is desirable to have two independent datasets collected under different conditions for use in developing a water quality model.

Water Quality Model

A water quality model is useful in evaluating conditions that would be difficult or costly to monitor directly. In general if a condition of maximum pollutant loading and critical ambient temperature and flow can be shown to result in attainment of standards, then attainment could be assumed for all conditions.

The EPA supported model QUAL2E, as recently modified for MDEP (ver. 4.1, July 2003), was used in the analysis of the Sabattus River. Steady state flows and load inputs are required and major transport mechanisms of advection and dispersion must be one dimensional. In general the Sabattus is well suited to this model. An exception is that a couple of sites on the lower river exhibit stratification at low flows. This was taken into account during the calibration procedure (see the section on Chemical Calibration).

The model was set up to represent the river as 25 reaches with two point source inputs (the Maine Electronics discharge was not included as it is a treated groundwater discharge) and three tributary inputs (see the model diagram in the Appendix, p. A3). DO, CBOD, phytoplankton (floating algae), nitrogen cycle and phosphorous cycle were modeled. Since the model output is in terms of daily averages, a diurnal adjustment must be applied in order to evaluate minimum daily DO. The diurnal adjustment is subtracted from the daily average value to provide the daily minimum DO for comparison to water quality criteria. The adjustment is based on the 2002 data (see 7Q10 With Diurnal section).

Model Transport

The 25 model reaches were defined based upon similar hydraulic properties. Advective transport is simulated by the model using velocity and volume (depth*width*length). Velocity and depth are represented as functions of flow through a power equation based on river transect data collected during the surveys. The functions are as follows:

$$\begin{aligned}\text{Velocity, fps} &= aQ^b \\ \text{Depth (average), ft} &= cQ^d\end{aligned}$$

Where: Q=flow, cfs
 a,b,c,d are calculated coefficients

Each reach is assigned specific coefficients calculated from transect data. The transect data were presented in the data reports. Much of the river is impounded and as such depth varies very little with flow. This is reflected in the coefficient values (d near 0).

Table 1 Hydraulic Coefficients

Reach	a	b	c	d
1	0.011	1	2.61	0
2	0.0064	1	2.259	0
3	0.0031	1	3.955	0
4	0.127	0.525	0.312	0.448
5	0.0292	0.664	0.608	0.566
6	0.1159	0.207	0.304	0.678
7	0.0434	0.705	0.401	0.579
8	0.039	0.595	0.779	0.377
9	0.076	0.433	0.430	0.478
10	0.008	0.928	3.600	0
11	0.0052	0.940	4.197	0.030
12	0.0036	0.940	4.899	0.030
13	0.0061	0.940	3.804	0.030
14	0.0055	0.940	4.356	0.030
15	0.0605	1.441	1.500	0
16	0.0047	0.940	3.720	0.030
17	0.0029	0.940	4.438	0.030
18	0.0026	0.940	4.562	0.030
19	0.0021	0.940	5.148	0.030
20	0.0016	1	6.379	0
21	0.0016	1	6.379	0
22	0.0019	1	4.823	0
23	0.0851	1.054	0.554	0.154
24	0.0020	0.940	4.090	0.030
25	0.0013	1	6.357	0

Dispersion or longitudinal spreading is less significant than advective transport and is calculated within the model using depth, velocity and a user supplied coefficient. In this case a coefficient value of 200 was used based on literature values for rivers with a similar velocity.

During each survey, mainstem streamflow was measured at both the beginning and end of the study area. Major tributary flows were also measured. Based on these measurements a flow balance was set up and any additional flow in the mainstem was accounted for in the model using incremental inflow along the length of the model reaches. All flow measurement results were included in the data reports.

The model segmentation is shown in a diagram in the appendix (p. A3).

Note: There was an error in the 2002 transect data as presented in the Sabattus River Data Report August 2002 Survey, April 2003, #DEPLW0591. Table 3 on page 6 of that report should be as follows:

Table 2 2002 Transect Data

		Ave.			
Transect	Width	Depth, ft.	Area, ft. ²	Flow, cfs	Vel, fps
T6	32.0	1.69	54.0	5.96	0.11
T7	37.3	1.68	62.4	6.00	0.10
T8	34.0	0.60	20.3	6.03	0.30
T9	35.0	1.03	36.0	6.04	0.17
T10	27.0	1.15	30.9	6.07	0.20
T11	34.4	1.14	39.2	6.07	0.15
T12	34.4	1.16	40.0	6.09	0.15
T13	23.8	1.38	32.7	4.45	0.14
T14	34.5	1.28	44.1	4.51	0.10
T15	34.3	1.47	50.2	4.55	0.09
T16	35.0	0.89	31.2	4.59	0.15
T17	39.7	3.60	142.8	4.90	0.03

Model Parameters and Rates

The following table lists the values used for various model parameters along with literature values (taken chiefly from the EPA QUAL2 manual). These parameters control the simulation of the various processes being modeled. In general the values were chosen by trial to result in good calibration of the model to the data while staying within accepted ranges. Table 4 depicts the values of the reach variable parameters.

Reaeration Coefficient

QUAL2 allows for various methods for the specification of reaeration rate. Normally option 3, O'Connor-Dobbins, is chosen. Although this option was used initially, it was determined based on experience and observation of the river characteristics that a number of model reaches required user specification of the reaeration rate. Reaches 5-9 required lower rates while reaches 17-22 and 24-25 generally required higher rates than O'Connor-Dobbins.

Chemical Calibration

The 2002 survey data were used to calibrate the water quality model for the Sabattus River. This calibration involved inputting measured tributary and treatment plant effluent chemical constituents as point source loads. Measured mainstem upstream constituents were used as boundary conditions and measured water temperature was specified as initial conditions. Incremental inflow was added along the mainstem to account for additional flow beyond that measured in the major tributaries. The loading for the incremental inflow was assumed equal to the mainstem boundary concentrations.

Table 3 Model Parameters/Rates

Parameter	Literature Values	Units	7Q10 model	Comment
latitude	-	deg	44.07	
longitude	-	deg	70.1	
standard meridian	-	deg	75	
start day	-	day	232	
evap coeff AE	0.00068	ft/hr-in HG	0.00068	
evap coeff BE	0.00027	ft/hr-in HG-mph	0.00027	
oxygen uptake per NH3	3.0-4.0	mgO/mgN	3.5	
oxygen uptake per NO2	1.0-1.14	mgO/mgN	1.0	
oxygen production per algae growth	1.4-1.8	mgO/mgA	1.4	
oxygen uptake per algae respiration	1.6-2.3	mgO/mgA	2.6	*
nitrogen content of algae	0.07-0.09	mgN/mgA	0.12	*
phosphorous content of algae	0.01-0.02	mgP/mgA	0.02	
algae growth rate	1.0-3.0	day ⁻¹	2.65	
algae respiration rate	0.05-0.5	day ⁻¹	0.45	
algae death rate	0-0.25	day ⁻¹	0.45-0.05	variable by reach. *
nitrogen half saturation	0.01-0.3	mg/l	0.025	
phosphorous half saturation	0.001-0.05	mg/l	0.0015	
linear shading	0.002-0.02	(1/ft)/(ug/l chl-a)	0.00268	
non linear shading	0.0165	(1/ft)/(ug/l chl-a) ^{2/3}	0.0165	
light function option	1,2,3	-	1	half saturation option
light saturation coeff. 1	0.02-0.1	BTU/ft ² -min	0.05	
light averaging option	1,2,3,4	-	4	
daylight hours	-	hrs	13.5	
total radiation, photo-active	-	BTU/ft ²	912	
light-nutrient option	1,2,3	-	2	
algal preference factor for NH3	0-1	-	0.5	
nitrification inhibition	10	-	10	
elevation	-	feet	200	
dust attenuation	0-.13	-	0.06	
cloudiness	0.0-1.0	-	0.3	
dry bulb temp	-	F	75	
wet bulb temp	-	F	62.4	
pressure	-	in. HG	30.1	
wind speed	-	ft/sec	12	
BOD decay	0.01-5.6	day ⁻¹	0.015	
BOD settling	(-0.36) - 0.36	day ⁻¹	0	
SOD	0.01-1.0	gm/ft ² /day	0.05-0.2	not measured
K2	various methods	day-1	opt 3, 1	see text
benthic BOD	-	mq BOD/ft ² -day	10	only in lower reaches
ON hydrolysis	0.02-0.4	day ⁻¹	0.02	
ON settling	0.001-0.1	day ⁻¹	0	
NH3 oxydation	0.1-1.0	day ⁻¹	0.15	
benthic NH3	function of SOD	mq/ft ² -d	0	
nitrite rate	0.2-2.0	day ⁻¹	0.2	
OP decay	0.01-0.7	day ⁻¹	0.01-0.02	higher in lower reaches
OP settling	0.001-0.1	day ⁻¹	0-0.02	mostly 0
benthic PO4	function of SOD	mq/ft ² -d	0.15	only in lower reaches
chl-a:A ratio	10-100	ug chl-a/mg A	50	
A settling	0.5-6.0	ft/day	0.3	0 in riffles
non algal extinction	0.01->	/ft	0.35	

*slightly out of range of literature values

Table 4 Reach Variable Parameters/Rates

Model Reach #	Reach Description	Model River Miles	Benthic CBOD Source mg / ft ² -day	Sediment Oxygen Demand gm/ft ² -day	Reaeration Rate Option	Reaeration Rate at 20° C (/day)		OP Settling (/day)	Benthic PO4-P (mg/ft ² -day)	OP Decay (/day)	Algae Settling (/day)	Algae Death (/day)				
-	Data Set -->	-	Both	Both	Both	2000	2002	Both	Both	Both	Both	Both				
1	Green St. bridge	-0.15 to -0.45	0	0.2	O-D	1.0	0.84	0	0	0.01	0.3	0.45				
2	Main St. bridge	-0.45 to -0.64				0.98	0.78									
3	bridge-dam	-0.64 to -0.72				0.29	0.24									
4	dam-Rt. 126	-0.72 to -0.87				10.4	13.5									
5	STP	-0.87 to -1.40		0.1	direct input	1.0	1.0									
6	~Jellison bridge	-1.40 to -1.78														
7		-1.78 to -2.39														
8		-2.39 to -3.11														
9	turnpike bridge-	-3.11 to -3.26		0.07	O-D	0.56	0.43									
10	Maxwell Stream-	-3.26 to -3.75				0.33	0.26									
11		-3.75 to -4.13				0.22	0.17									
12		-4.13 to -4.39				0.42	0.33									
13	gravel pit	-4.39 to -4.89		0.05	O-D	0.33	0.26									
14	down to falls	-4.89 to -5.23		0		6.25	3.9									
15	falls	-5.23 to -5.27				0.14	0.19									
16	OBD	-5.27 to -5.98														
17		-5.98 to -6.44	10	0.07	direct input	0.18	0.18	0.15	0.02	0.3	0.40					
18	-King Rd.	-6.44 to -6.89									0.35					
19		-6.89 to -7.27									0.3					
20	No Name	-7.27 to -7.69														
21	Moody Rd.	-7.69 to -8.11														
22	-Lisbon dam	-8.11 to -8.41				0	O-D				22.1	18.1	0	0	0	0.1
23	below dam	-8.41 to -8.52									0.25	0.27				
24	Barker brook	-8.52 to -9.09									0.18	0.19				
25	-Mill St.	-9.09 to -9.43				10					direct input			0.02	0.15	0.02

O-D = Oconnor Dobbins

The model output of various constituents such as CBOD, chl-a and DO are compared to the survey data and adjustments made to model parameters until a good match is achieved. The model is then verified by substituting the 2000 survey data point loads, boundary conditions, flows and initial conditions; re-running the model; and comparing to the measured 2000 data. If necessary minor adjustments are made to the model parameters to achieve an acceptable fit for both datasets.

The following charts present the model predictions and observed data for various chemical constituents for the 2002 and 2000 datasets.

Dissolved Oxygen

A very good fit was achieved for the 2002 data. The error bars indicate the variation of daily average DO among the three survey days. The model DO output represents daily average values assuming one dimensional flow. The data at the sites between rivermile -6.9 and rivermile -8.4 indicate some thermal stratification. This stratification reduces mixing of the bottom water. The DO measurements just above the river bottom were very low and tended to significantly lower the depth averaged DO. Therefore the measured DO for these sites were represented on the chart as depth averages with and without the deepest readings with a model prediction between these values being acceptable.

The fit to the 2000 data is generally good. These data were collected at a higher river flow (71% greater than 2002 and 4 times greater than the designated minimum dam release). Thermal stratification was almost entirely eliminated at this higher flow. Note that two data points near mile -8 were surface readings (bank samples) only and little weight was placed on these with regard to model comparison. The objective is to develop an accurate low flow model so that a match to the 2002 data (representing drought conditions) is more important, with the 2000 data/conditions serving as verification.

Figure 1 Sabattus Model Daily Average DO, 2002 Survey

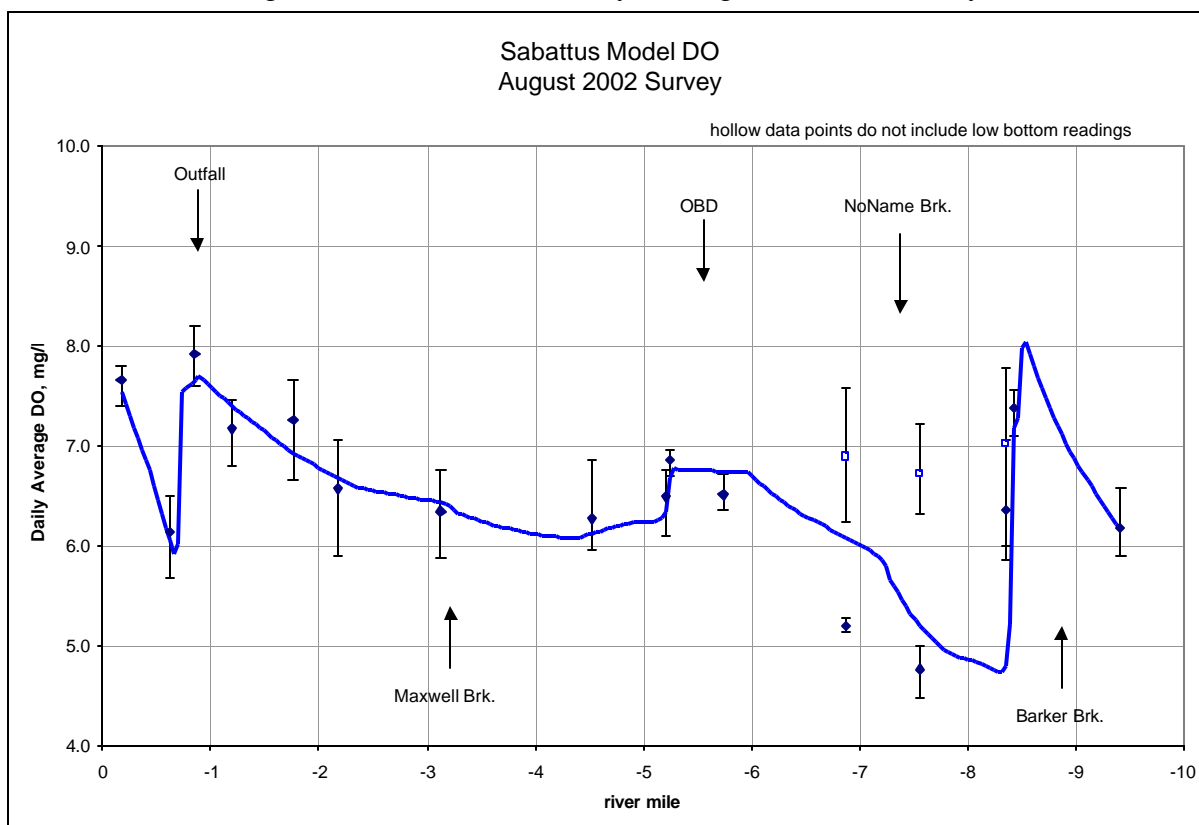
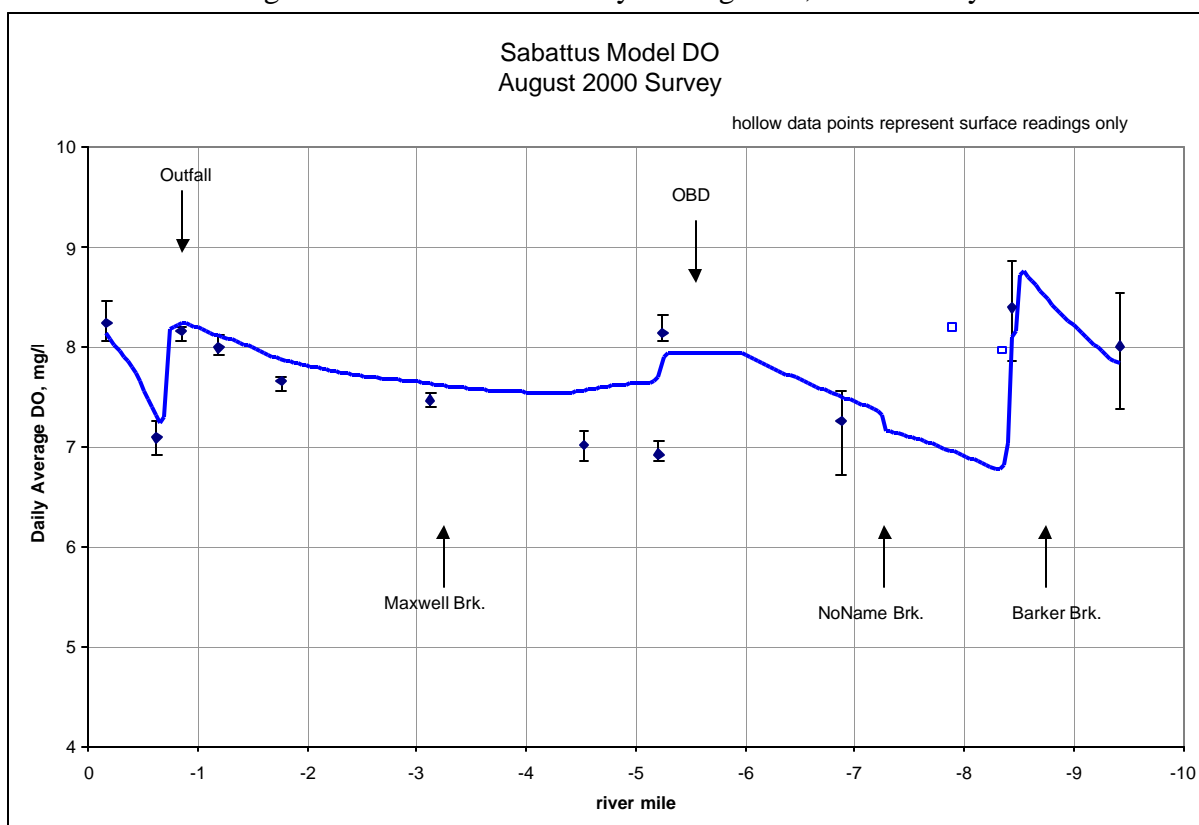


Figure 2 Sabattus Model Daily Average DO, 2000 Survey



CBOD

The CBOD results may have been increased by the algae content of the samples, so a correction¹ based on chl-a concentration of the sample was subtracted from the CBOD data to account for algal respiration. The match is not bad for 2000 but is not good for the downstream reaches for 2002. This mismatch may be due to interference by algal respiration not accounted by the correction. It was decided to accept the CBOD calibration. This decision is supported by the low sensitivity of the model to CBOD loading (see the section on Sensitivity Analysis).

Figure 3 Sabattus Model CBOD, 2002 Survey

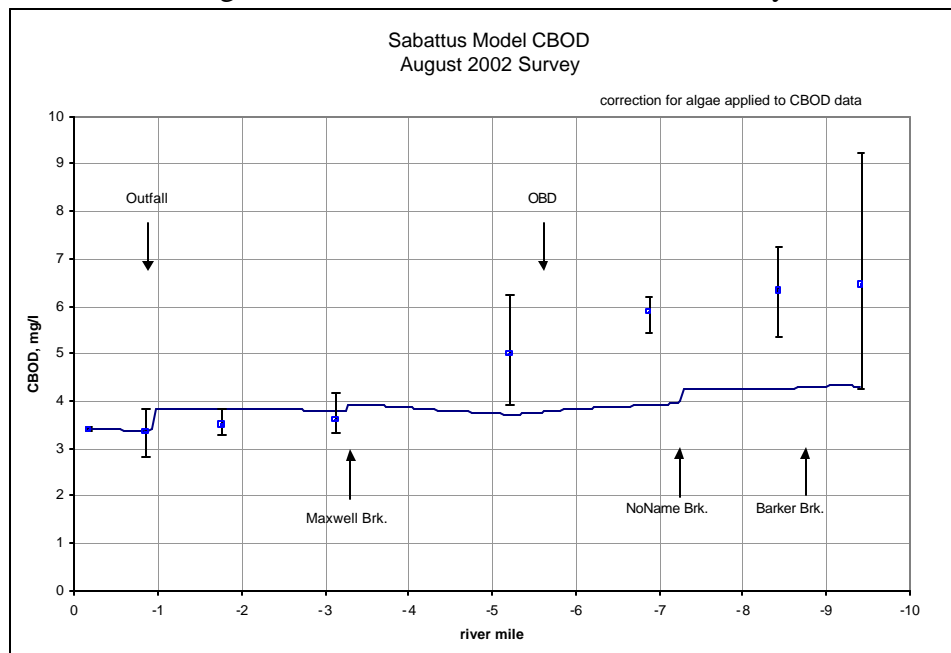
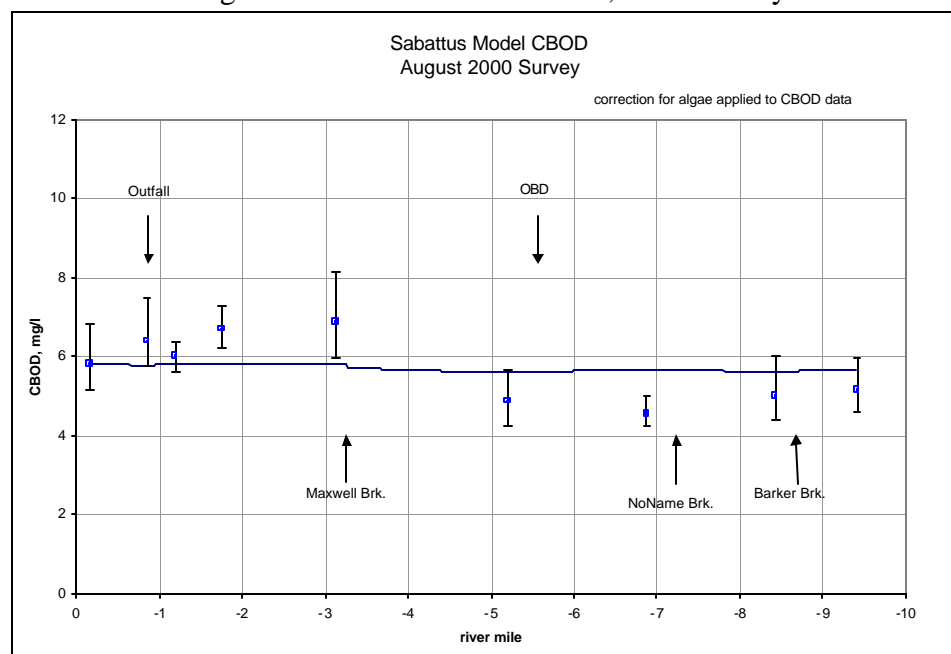


Figure 4 Sabattus Model CBOD, 2000 Survey



¹ correction = chl-a (mg/l) x 30 (carbon:chlorophyll ratio) x 2.67 (oxygen:carbon ratio)

Phytoplankton (chl-a)

A very good match was achieved with the 2002 data with an acceptable match for the 2000 data. Note that during 2000 there was a higher loading of algae from the Sabattus Pond (upstream boundary).

Figure 5 Sabattus Model chl-a, 2002 Survey

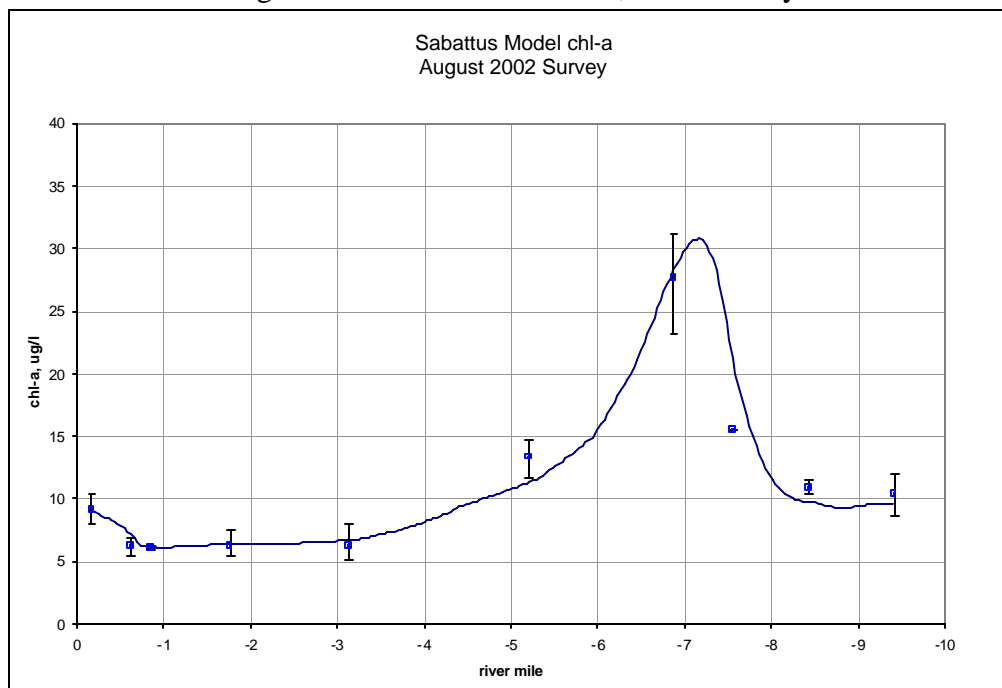
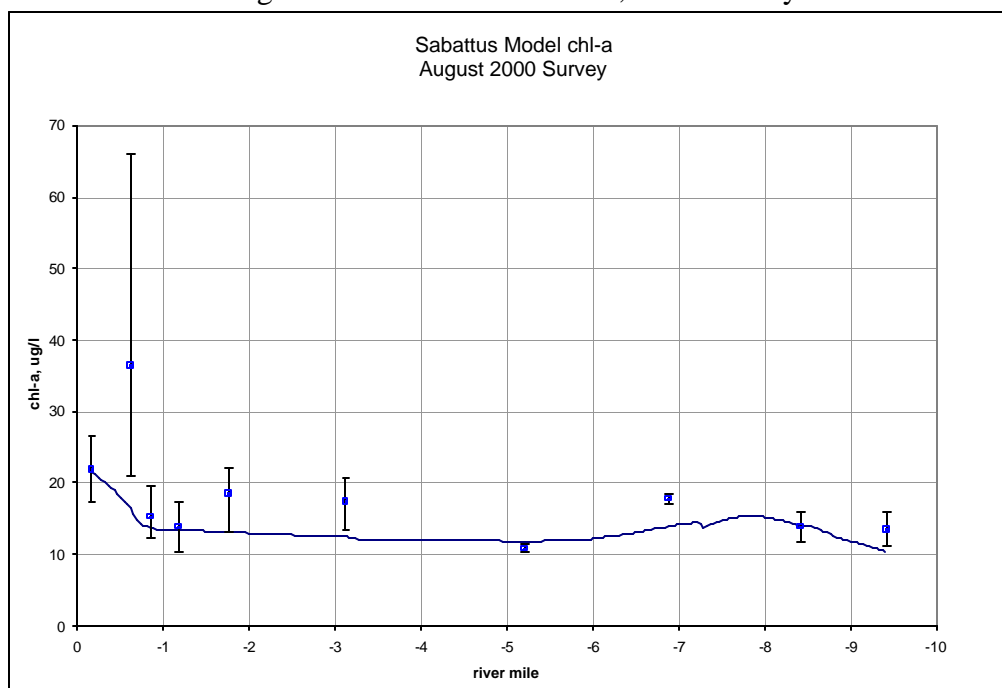


Figure 6 Sabattus Model chl-a, 2000 Survey



Nutrients

The matches for total phosphorous (TP) and total nitrogen (TN) were very good for the 2002 data. The matches for the 2000 data were acceptable although in each case two sites (miles -1.76 and -3.13) were not simulated well by the model.

Figure 7 Sabattus Model TP, 2002 Survey

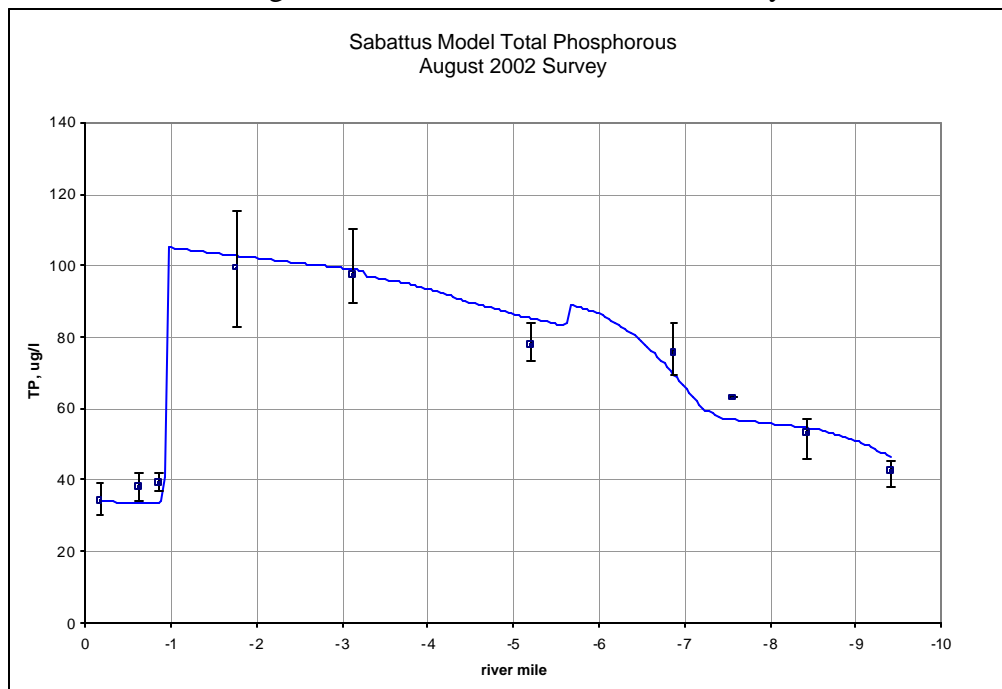


Figure 8 Sabattus Model TN, 2002 Survey

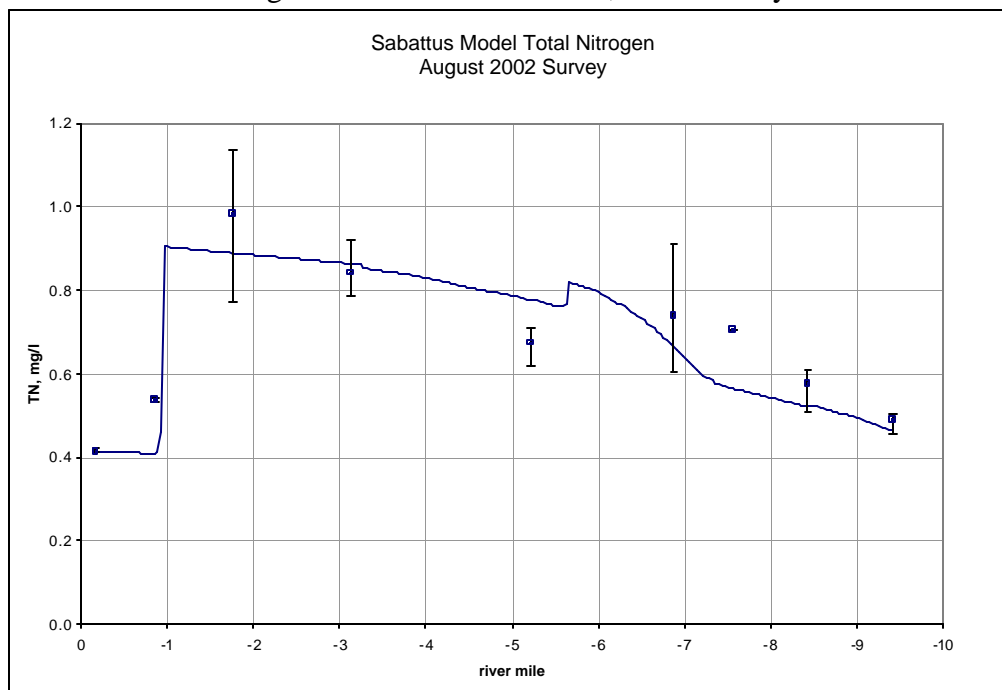


Figure 9 Sabattus Model TP 2000 Survey

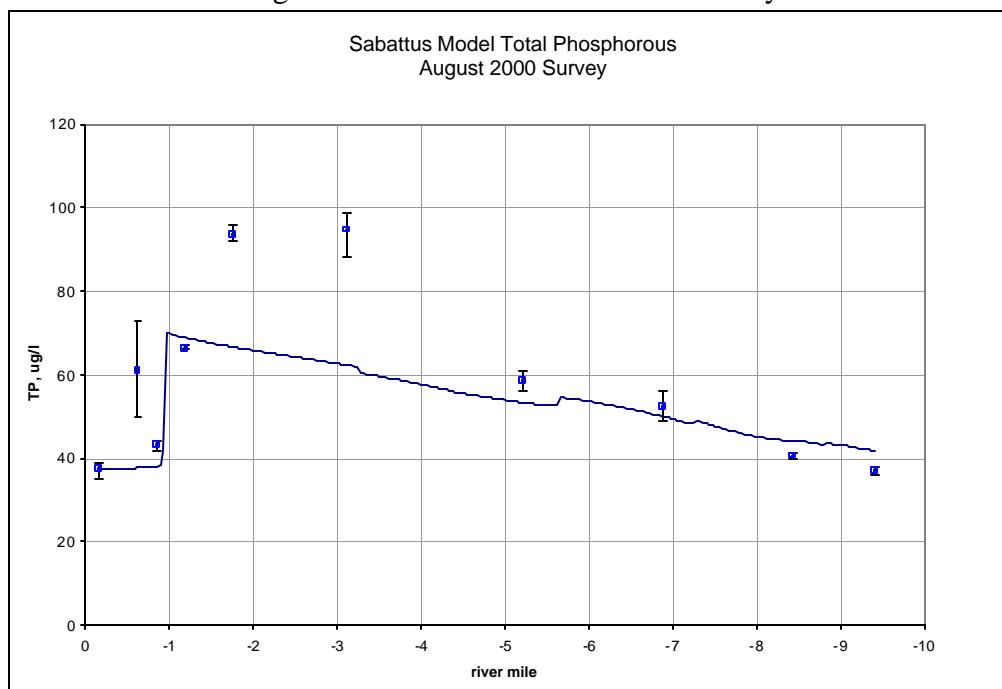
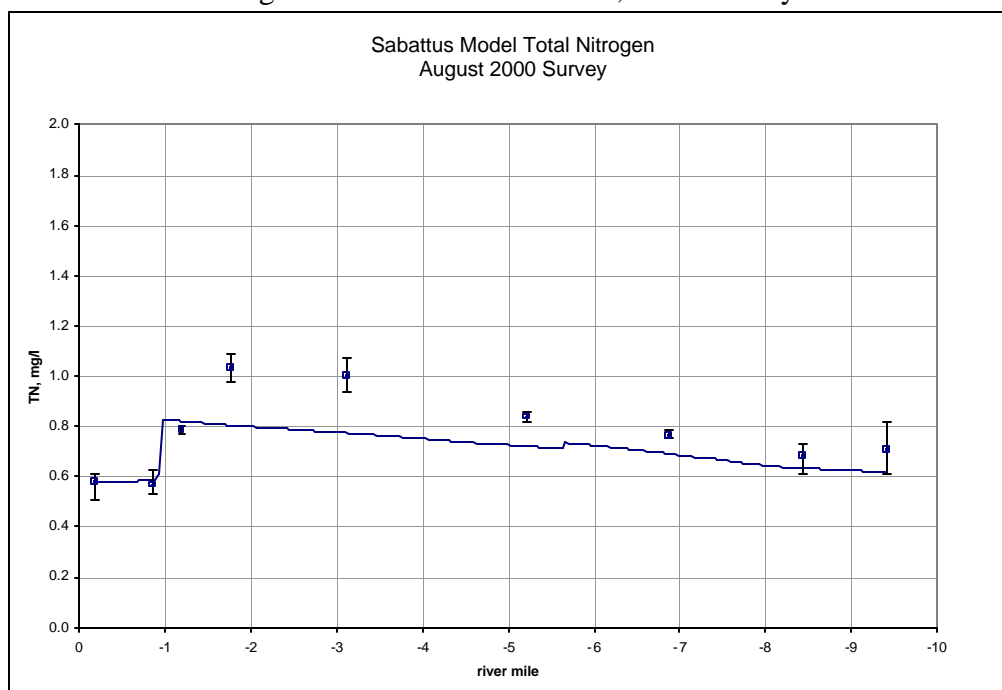


Figure 10 Sabattus Model TN, 2000 Survey



Sensitivity Analysis

In a sensitivity analysis, parameter rates are varied to determine their relative impact upon the results of a model. The 2002 calibration model was used as the basis for the sensitivity analysis runs. Each parameter investigated was decreased and increased by 50% and the model results for DO were compared to the original output. The results for an analysis of CBOD decay rate, SOD (sediment oxygen demand) rate, reaeration rate and phytoplankton growth rate are shown in the tables below.

Table 5 Daily Average Dissolved Oxygen Sensitivity, DO change, mg/l

Base Case		BOD Decay Rate		SOD Rate		Reaeration Rate		Growth Rate	
Location*	Model	-50%	+50%	-50%	+50%	-50%	+50%	-50%	+50%
-0.66	5.92	0.02	-0.02	1.01	-1.01	-0.38	0.42	-0.03	0.04
-4.38	6.06	0.06	-0.06	1.23	-1.23	-1.32	0.77	-0.17	1.04
-8.28	4.72	0.15	-0.13	1.38	-1.38	-2.41	1.07	0.47	0.33
-9.41	6.18	0.10	-0.07	0.91	-0.91	-0.97	0.49	0.17	0.00

*sag points, rivermile

Table 6 Daily Average Dissolved Oxygen Sensitivity Range**, mg/l

Base Case		BOD Decay	SOD	Reaeration	Growth Rate
Location*	Model				
-0.66	5.92	0.03	2.02	0.80	0.07
-4.38	6.06	0.12	2.46	2.10	1.21
-8.28	4.72	0.28	2.76	3.48	0.80
-9.41	6.18	0.17	1.81	1.47	0.17

*sag points, rivermile

**parameter varied -50% to +50% from calibration value

Based on the above analysis the most important parameters in the DO calibration of the model include reaeration rates and SOD values. The reaeration rates were chosen based on established methods (O'Connor-Dobbins, literature values) with only small adjustments made for a few reaches based on experience and observation of the river characteristics. The SOD values are more uncertain. SOD is the direct utilization of dissolved oxygen by the sediments through chemical and biological oxidation. SOD can be a natural component of the sediment or can originate from the settling of organic loading to the river. That significant SOD exists in the Sabattus River is supported by low water column DO readings near the river bottom at the deeper sites. The SOD values chosen for the model provide the best calibration of the low flow dataset and are within literature values. The following table compares the Sabattus SOD values with measured values from other DEP projects. The maximum SOD rate chosen for the Sabattus River is low compared to measured maximum values. Therefore it is reasonable to conclude that the model does not overstate the impact of SOD.

Table 7 SOD in Maine Rivers

MDEP Project	measured SOD, gm/ft2/day		
	max	ave	min
Kennebec Estuary	0.24	0.11	0.004
Kennebec River	0.52	0.13	0.01
Piscataquis River	0.24	0.15	0.10
Royal Estuary	0.30	0.22	0.11
Penobscot River	0.32	0.23	0.13
Penobscot Estuary	0.35	0.24	0.16
Mousam Estuary	0.37	0.25	0.18
Sabattus*	0.2	-	0

*range of estimated values used in model

7Q10 Predictive Model

After a model is calibrated to observed data, prediction runs are made at critical conditions to evaluate compliance with DO standards. Critical conditions normally include low flow (7Q10¹ is required by statute), high temperature and dischargers at permitted loads. In the case of the Sabattus River, low flow is considered to be the minimum required flow from the pond outlet dam (2.5 cfs) and this will be taken as the 7Q10 flow. A temperature of 74.3° F (23.5°C) was assumed for the low flow runs, which is approximately equal to the daily average of the river during the 2002 survey.

Non point loads are accounted for as tributary and incremental inflow loads, with flows equal to the 2002 conditions (because they represented drought conditions). Non point loading is also indirectly accounted for through the specification of SOD (see section on sensitivity). Constituent chemical concentrations for the boundary loads were generally taken as the average of the two surveys, except that the boundary (pond outlet) chl-a was set at the 2000 measured value, representing a blooming pond. All parameters and rates were kept unchanged from the August 2002 model including the light variables.

Licensed point source loads are inputted at their permitted weekly loads (flow and concentration) for the 7Q10 runs. In the case of non licensed constituents (nutrients), loading is taken from the survey data. The CBOD load must be derived from the permit limits for BOD5 (five day biochemical oxygen demand) and a CBOD/BOD5 ratio calculated from the survey data (see appendix for permit limits).

Table 8 Point Source Permit Loads for Model Input

	Flow cfs	temperature F	DO mg/l	CBOD _u *, mg/l		ON mg/l	NH3 mg/l	NO3 mg/l	OP mg/l	PO4 mg/l
				weekly	monthly					
Sabattus Sanitary District	0.186	65.8	8.1	238.5	90.1	2.2	0.32	28.8	0.317	4.06
Gerard Begin OBD	0.031	68	5	(283.5)	189	0.76	0.94	15	0.1	1.5

*Sabattus CBOD/BOD5 ratio = 5.3; OBD ratio = 6.3

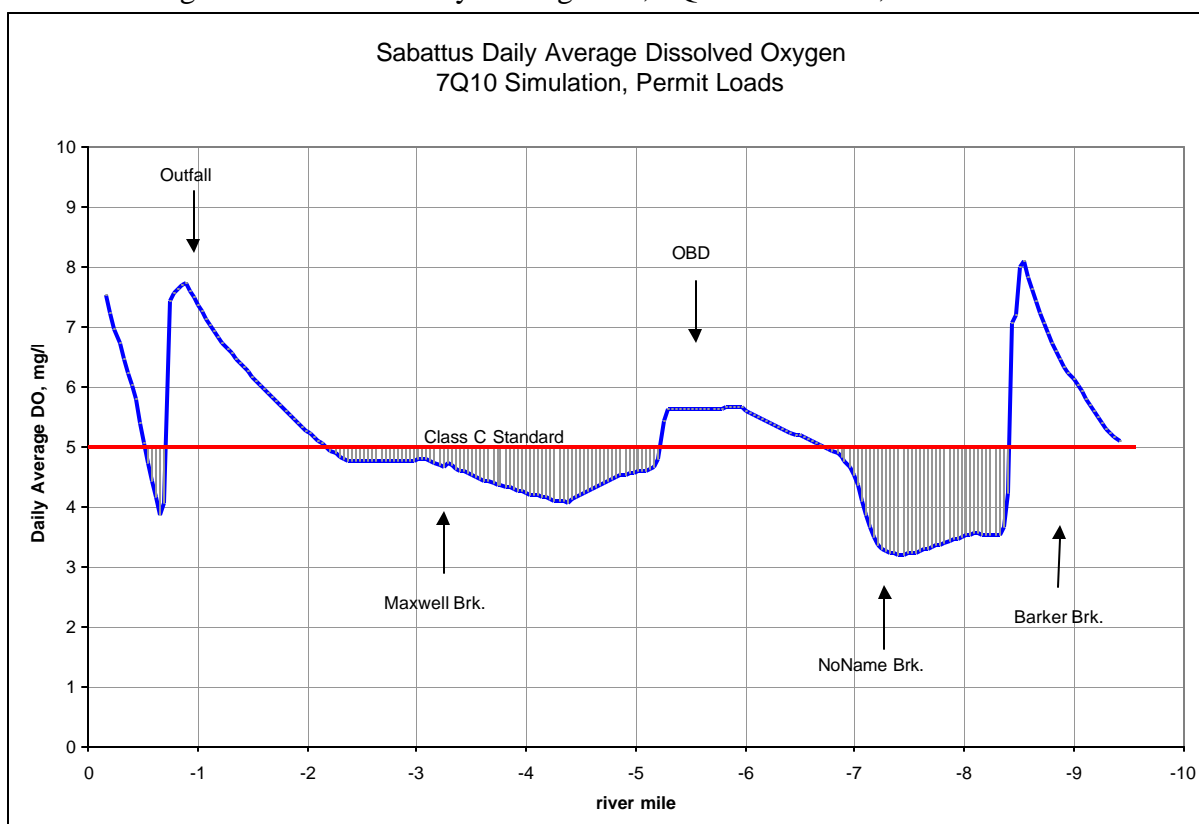
Runs With Predictive Model

7Q10

The results of the low flow, license load DO simulation are shown in the following figure. This shows daily average DO only and does not account for diurnal variation.

¹ 7 day average low flow with probability of occurring once in 10 years

Figure 11 Sabattus Daily Average DO, 7Q10 Simulation, Permit Loads



7Q10 with Diurnal

The output of the above QUAL model run represents daily average conditions (steady state model). Water quality standards for minimum DO are in terms of instantaneous DO. When algae is present in significant amounts a diurnal DO effect is generally observed. The algae produce oxygen during daylight hours but only consume oxygen during the night so that the lowest DO concentrations occur near dawn and the highest DO concentrations occur in the afternoon. One method used to represent this effect is to bracket the daily average model output with a diurnal range. A relationship between chl-a concentration and diurnal DO range was developed using the data from the 2002 survey (see figure 12). To obtain the daily minimum DO, $\frac{1}{2}$ the diurnal range, as calculated from the chl-a output, is subtracted from the average daily DO output. The results of the low flow, license load minimum daily DO simulation are shown in figure 13 with the diurnal range indicated by shading. These results indicate that 7.2 miles (77% of the study segment) of river do not comply with class C DO criteria.

Figure 12 Diurnal DO vs chl-a, 2002 data

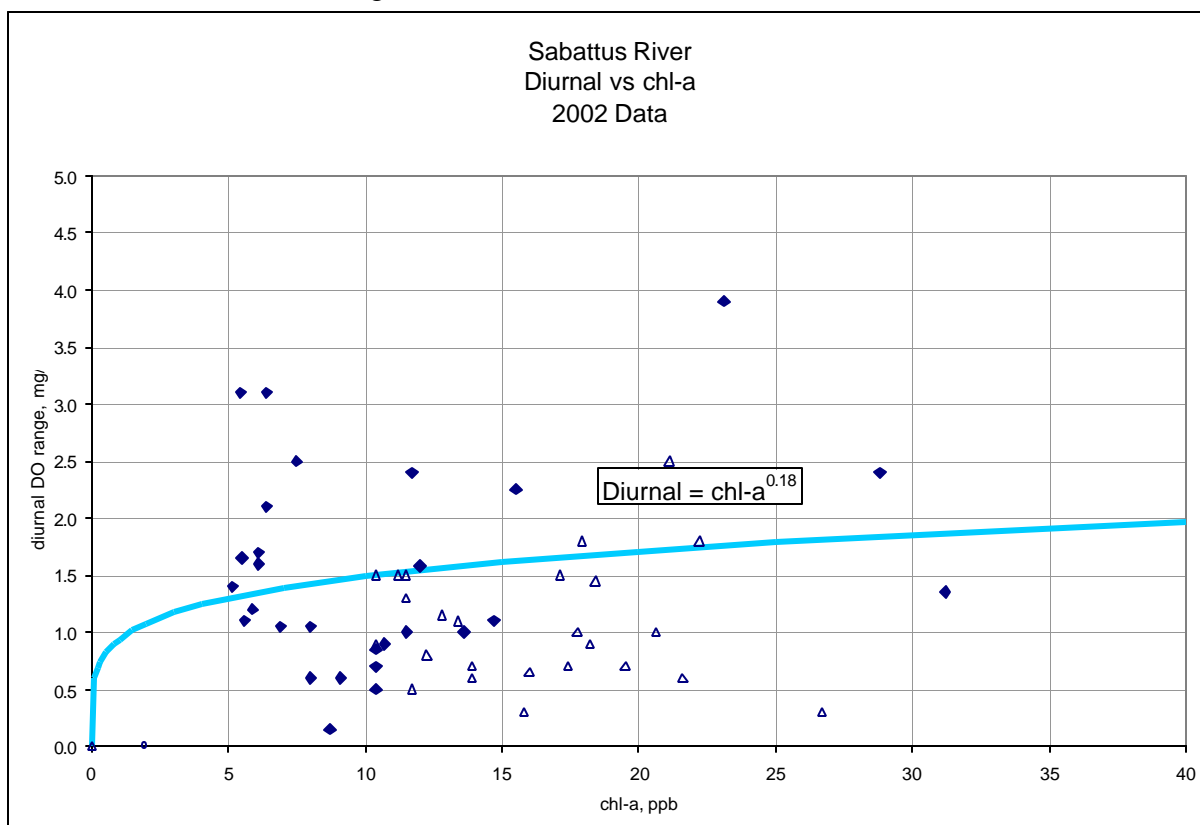
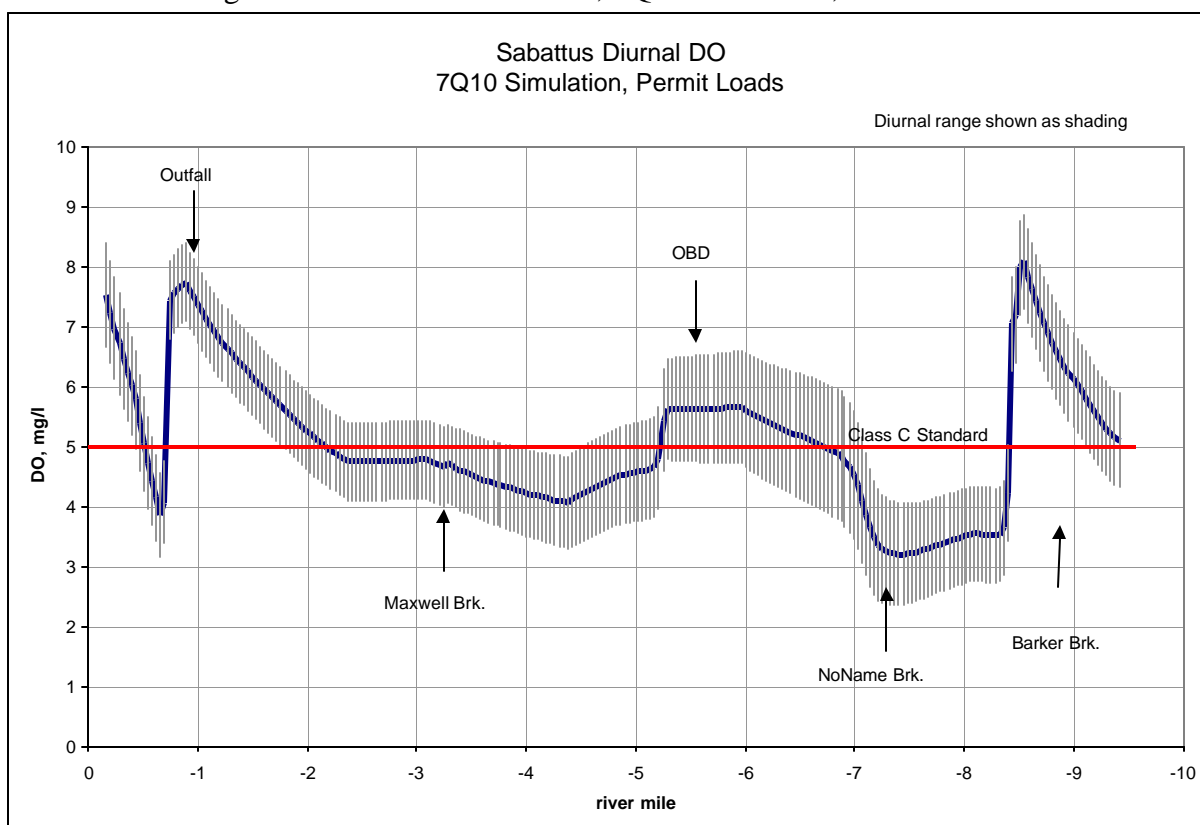


Figure 13 Sabattus Diurnal DO, 7Q10 Simulation, Permit Loads



Component Analysis

In a component analysis, potential impacts to water quality degradation (in terms of depletion of dissolved oxygen) are individually removed from the predictive model and the increase in DO observed. The depletion of DO concentration relative to 100% saturation can then be determined. A component analysis was made for the Sabattus River. The model was run at 7Q10 conditions and full permit loads. The impacts were evaluated in terms of minimum daily DO. The following pie charts present the results for the three non-attainment “sag” locations on the river. It should be noted that this analysis assumed no change in river hydraulics (no removal or change in operation of existing dams) and that NBOD is the utilization of oxygen through oxydation of nitrogen.

Figure 14 DO Depletion Analysis Rivermile -0.66

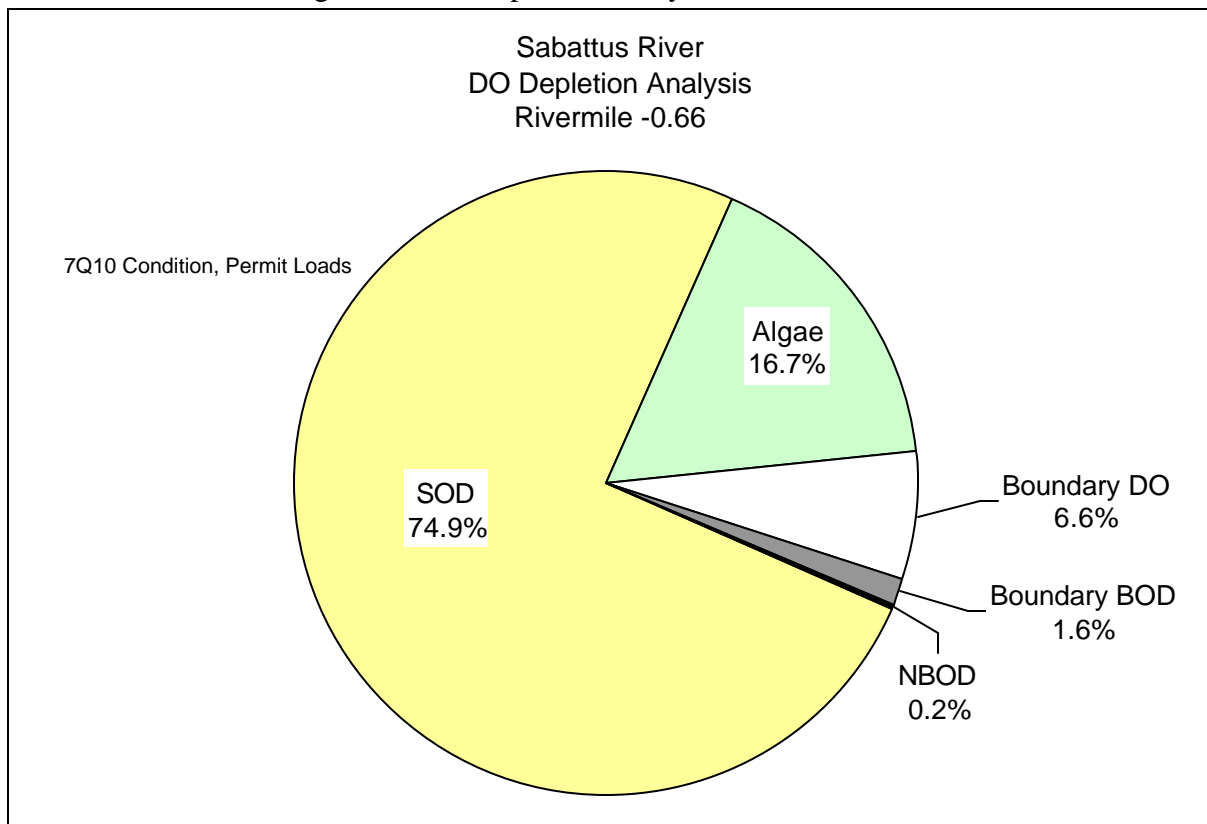


Figure 15 DO Depletion Analysis Rivermile -4.38

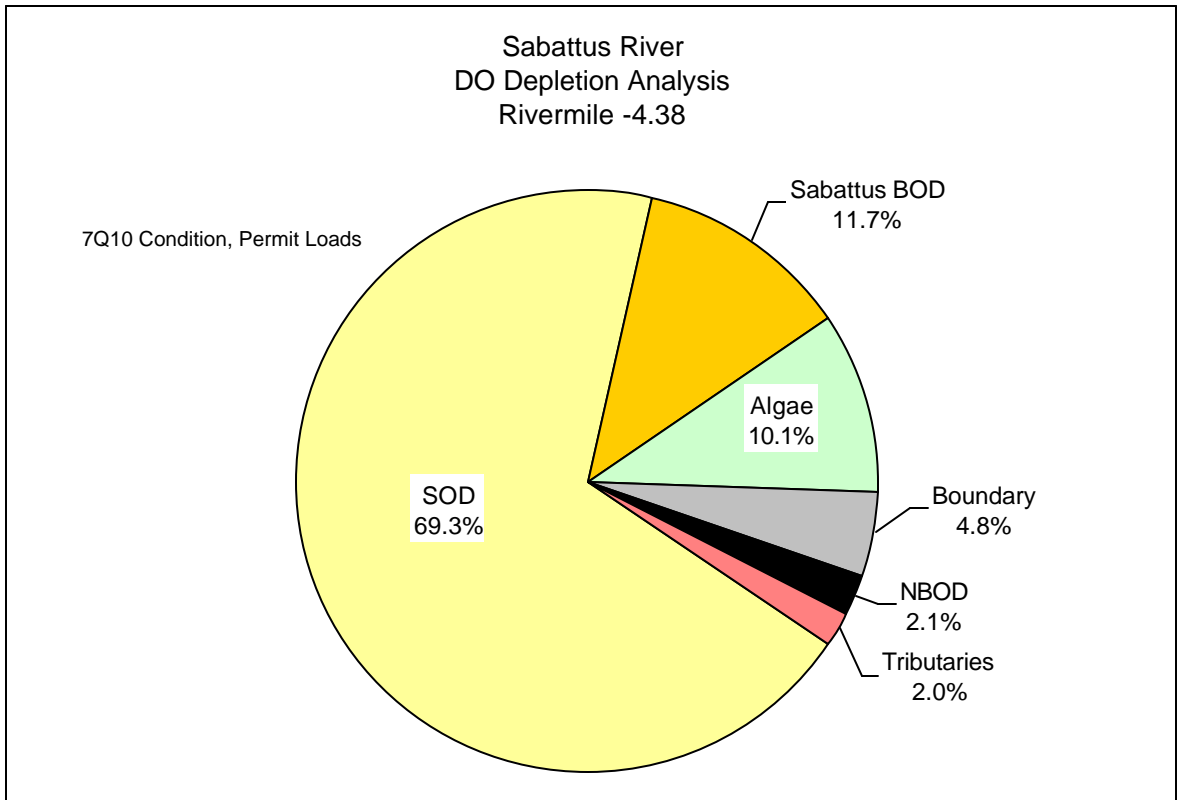
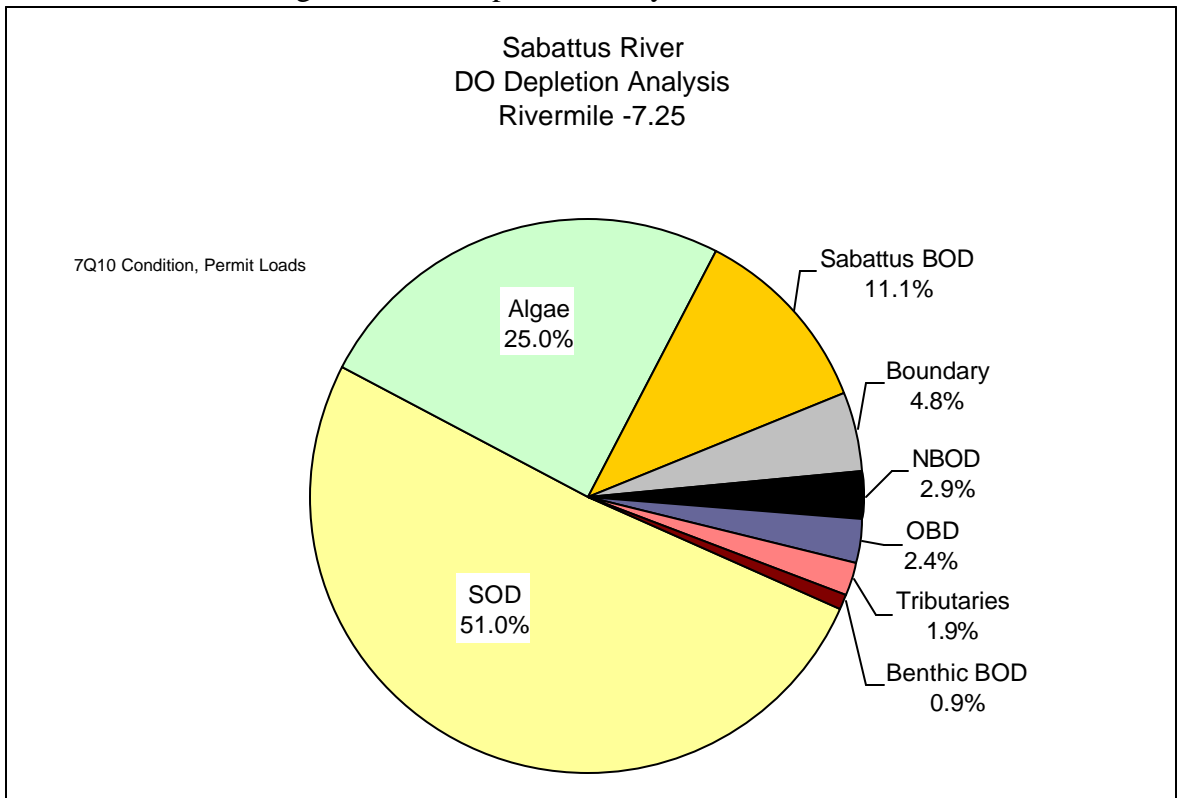
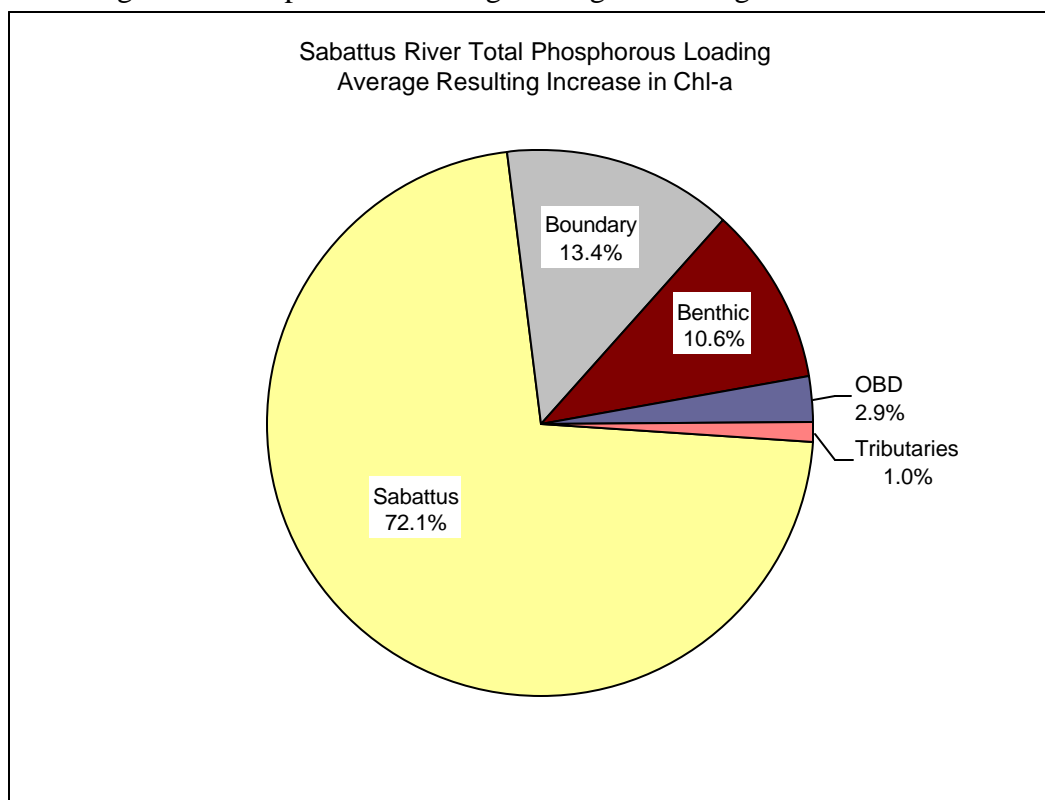


Figure 16 DO Depletion Analysis Rivermile -7.25



Although algae is shown as a separate “component” in the previous charts, algae growth is a result of nutrient loading from other components. The following chart depicts the effect of the various phosphorous loads/sources on algae growth (in terms of chl-a). Specifically, the chart shows the percent increase in average chl-a concentration in the river due to each source of phosphorous.

Figure 17 Phosphorous Loading-Average Resulting Increase in Chl-a

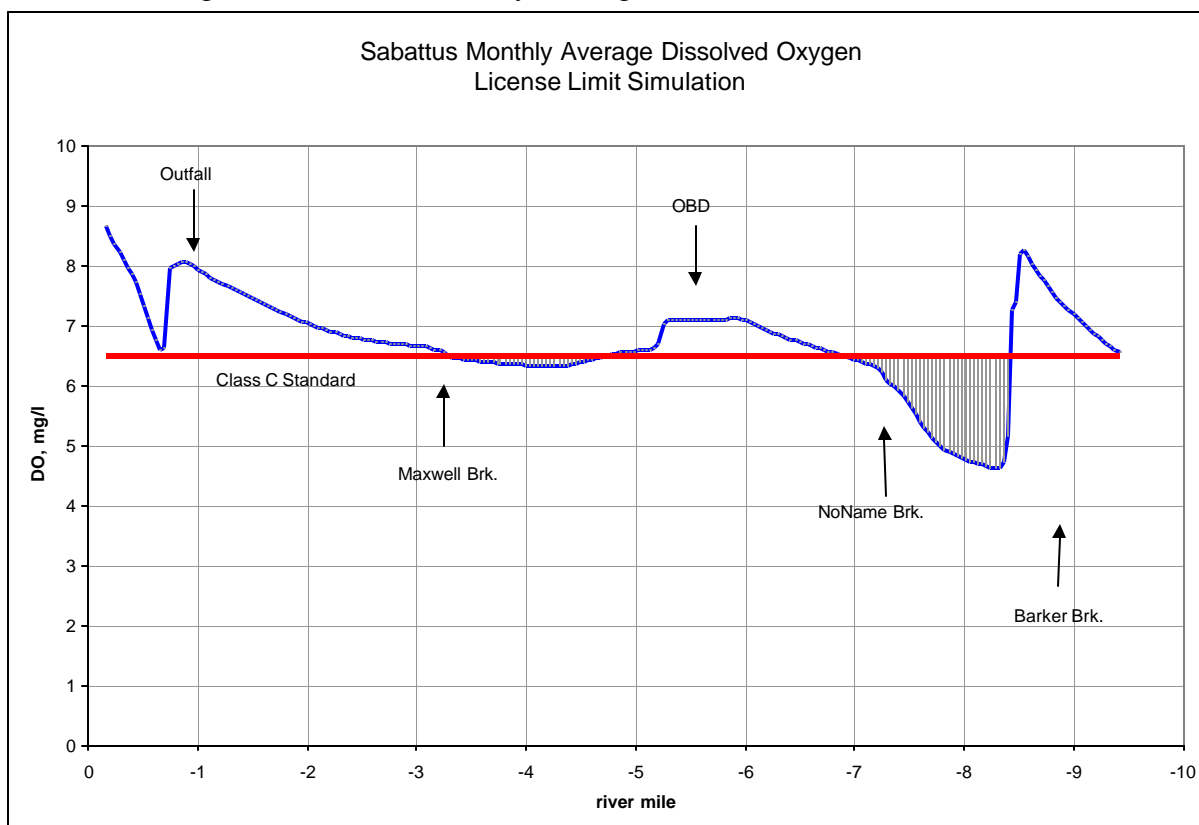


Monthly Average Flow

In addition to a low flow (7Q10) run, an average monthly low flow (30Q10¹) run is also made to evaluate the monthly average DO criteria of 6.5 mg/l. Statistics for the Little Androscoggin River indicate a 30Q10 flow to 7Q10 flow ratio of 1.6, which would result in a 30Q10 flow at Sabattus Pond dam of 4 cfs (assuming 7Q10 flow equals the minimum flow at the dam). Because the flow during the 2002 study was 5.8 cfs during an extended dry period, a somewhat higher 30 day low flow equal to twice that used for the 7Q10 model was assumed. This results in a 30Q10 flow of 5 cfs at the outlet dam. Temperature for the 30Q10 model was decreased to 22C (71.6 F). Point source CBOD loadings were based on monthly average permit levels. The results of the 30Q10, license limit DO simulation are shown in the following figure. These results indicate that 3.0 miles (32% of the study segment) of river do not comply with class C DO criteria although almost half of this mileage is very close to the required 6.5 mg/l concentration.

¹ 30 day average low flow with the probability of occurring once in 10 years

Figure 18 Sabattus Monthly Average DO, License Limit Simulation



Performance

7Q10 and 30Q10 model runs were made with the point sources at performance loads (see table). This is the actual average discharge loading over the past 5 years in terms of flow and BOD. For Sabattus SD performance BOD weekly and monthly mass loading are 14% and 33% of permit levels, respectively.

Table 9 Point Source Performance Loads (5 year average)

	Flow cfs	CBOD _u *, mg/l		ON** mg/l	NH ₃ ** mg/l	NO ₃ ** mg/l	OP** mg/l	PO ₄ ** mg/l
		weekly	monthly					
Sabattus Sanitary District	0.138	44.5	40.3	2.2	0.32	28.8	0.317	4.058
Gerard Begin OBD	0.026	25.8	NR	0.76	0.94	15	0.1	1.5

*Sabattus CBOD/BOD5 ratio = 5.3; OBD ratio = 6.3

**from survey data

NR-not reported

The modeling results are shown on the following charts. Non-attainment miles are 6.1 and 3.0 for the 7Q10 and 30Q10 performance runs respectively.

Figure 19 Sabattus Diurnal DO, 7Q10 Simulation, Performance Loading

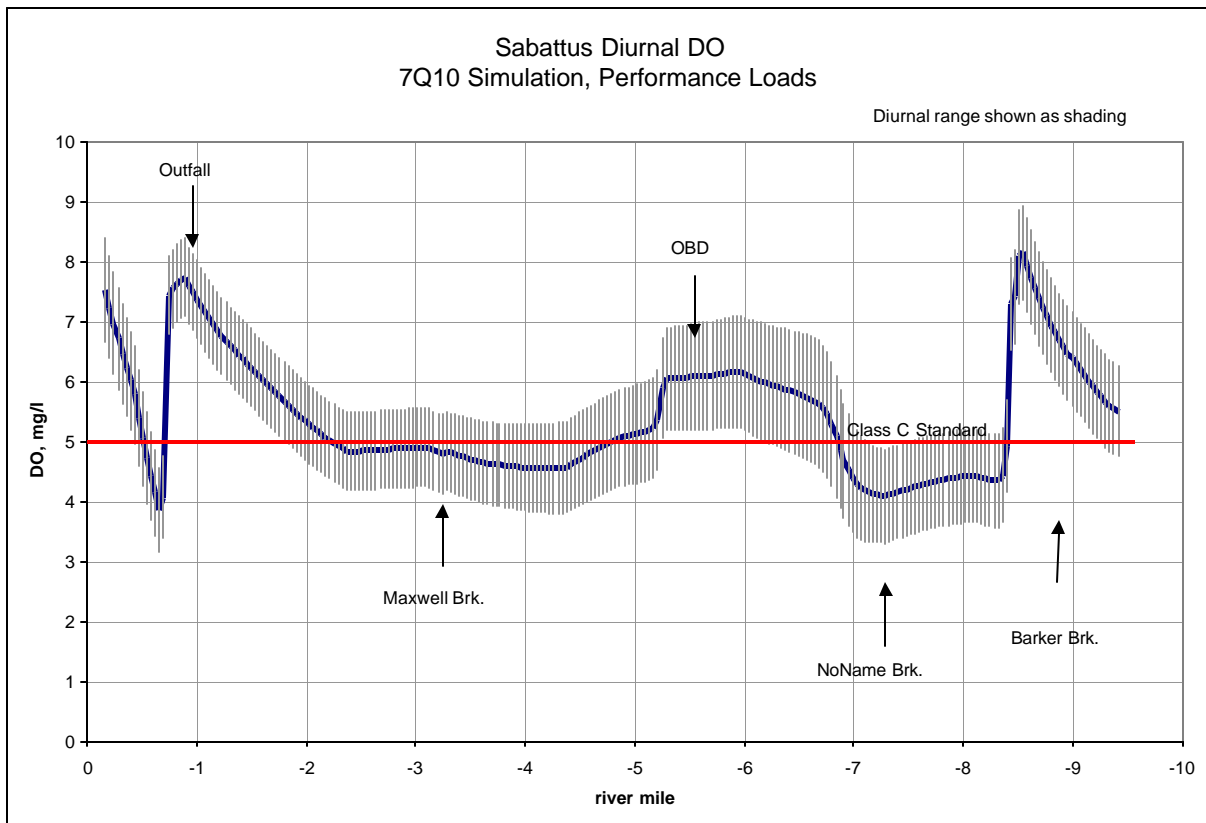
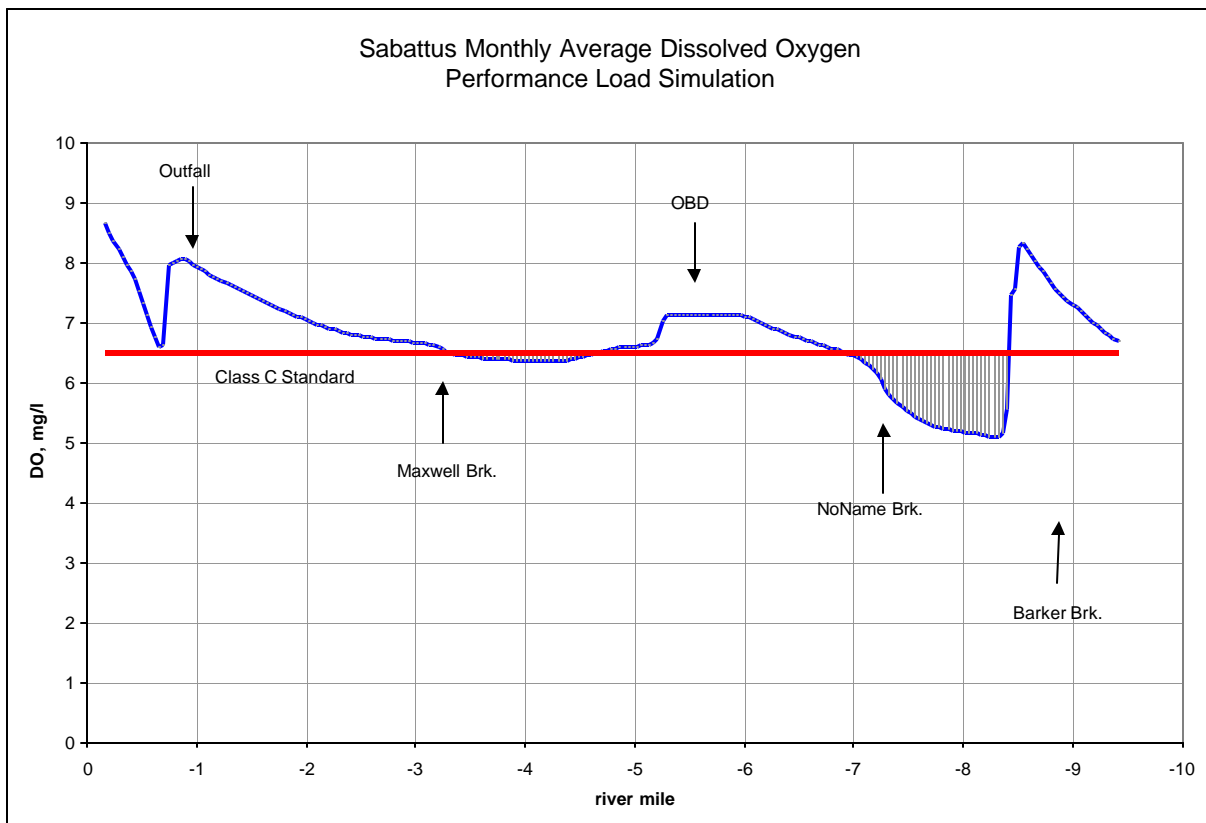


Figure 20 Sabattus Monthly Average Dissolved Oxygen, Performance Loads



Modeling Scenarios

A water quality model can also be used to investigate loading scenarios in terms of improving the predicted instream DO. A number of scenarios were run with the results shown in the following table:

Table 10 Model Scenarios

Input File	Flow conditions	Scenario	Minimum DO (chl-a, ppb), mg/l			Maximum chl-a, ppb	River miles in Non attainment	River miles with algae blooms
			Above Sabattus Outfall	Above Falls	Below Falls			
SAB7QG.inp	2.5 cfs (7Q10)	License loads, reduced SOD 50%	5.2 (6.9)	5.1 (10.8)	3.8 (18.9)	75.9	1.4	5.9(63%)
SAB7QC.inp	5 cfs	Performance loads, 5 cfs min.	4.9 (13.4)	4.9 (15.8)	3.8 (10.2)	41.9	2.8	9.3(100%)
SAB7QL.inp	2.5 cfs (7Q10)	No dams, zero discharges	6.7(18.4)	3.8(0.7)	5.8(1.7)	21.6	3.5	1.7(18%)
SAB7QB.inp	5 cfs	License loads, 5 cfs min.	5.0 (12.0)	4.7 (16.9)	3.1 (11.2)	54.6	3.9	9.3(100%)
SAB7QK.inp	2.5 cfs (7Q10)	Licence loads, all modeled dams removed	6.7(18.4)	3.5(27.7)	4.85(48.1)	94.6	4.2	9.3(100%)
SAB7QF.inp	2.5 cfs (7Q10)	Licence loads, two Lisbon dams removed	3.1 (6.9)	3.3 (10.8)	4.6 (83.7)*	147.2	4.2	5.9(63%)
SAB7QE.inp	2.5 cfs (7Q10)	Licence loads, upper Lisbon dam removed	3.1 (6.9)	3.3 (10.8)	2.3 (16.8)*	136.0	4.7	5.9(63%)
SAB7QPER.inp	2.5 cfs (7Q10)	Performance loads	3.1 (6.9)	3.8 (10.2)	3.3 (12.0)	62.5	6.1	5.9(63%)
SAB7QA.inp	2.5 cfs (7Q10)	Zero discharges	3.1 (6.9)	3.9 (0.4)	3.8 (10.4)	17.2	6.1	1.6(17%)
SAB7QD.inp	2.5 cfs (7Q10)	Licence loads, Fortier dam removed	6.7 (18.4)	3.5 (27.7)	2.6 (13.6)	67.1	6.6	9.3(100%)
SAB7QH.inp	2.5 cfs (7Q10)	SAB TP treatment 0.5 mg/l	3.1 (6.9)	3.2 (4.7)	3.1 (9.7)	16.6	7.2	3.6(39%)
SAB7Q.inp	2.5 cfs (7Q10)	License loads	3.1 (6.9)	3.3 (10.8)	2.4 (20.2)	75.9	7.2	5.9(63%)
SAB30QD.inp	10 cfs	Performance loads	7.6(17.1)	7.1(17.9)	5.7(11.7)	26.8	1.1	9.3(100%)
SAB30QP.inp	5 cfs (30Q10)	Performance loads	6.6 (13.9)	6.35 (14.3)	5.1 (10.5)	37.7	3.0	9.3(100%)
SAB30Q.inp	5 cfs (30Q10)	License loads	6.6 (13.9)	6.3 (14.4)	4.6 (14.6)	47.5	3.0	9.3(100%)
SAB30QA.inp	5 cfs (30Q10)	Zero discharges	6.6 (13.9)	6.1 (1.2)	5.7 (6.2)	13.9	4.4	2.0(21%)

*sag moved down to mill dam inpondment

7Q10 Runs

The modeling results indicate that SOD, in combination with the river impoundments, has the major impact upon DO in the river. The non attainment occurs in impounded sections of the river including the impoundments behind existing dams and a naturally impounded area above the falls at Crowley Road (between rivermiles -3 and -5). In these areas velocities are reduced and time of travel is increased resulting in longer exposure to sediments, increased algae growth and reduced reaeration. If the dams were removed, non attainment would be essentially eliminated except for the naturally impounded section of the river.

River flow is another major factor in river DO. An increase in 7Q10 flow from 2.5 cfs to 5 cfs would reduce non attainment miles by 46%.

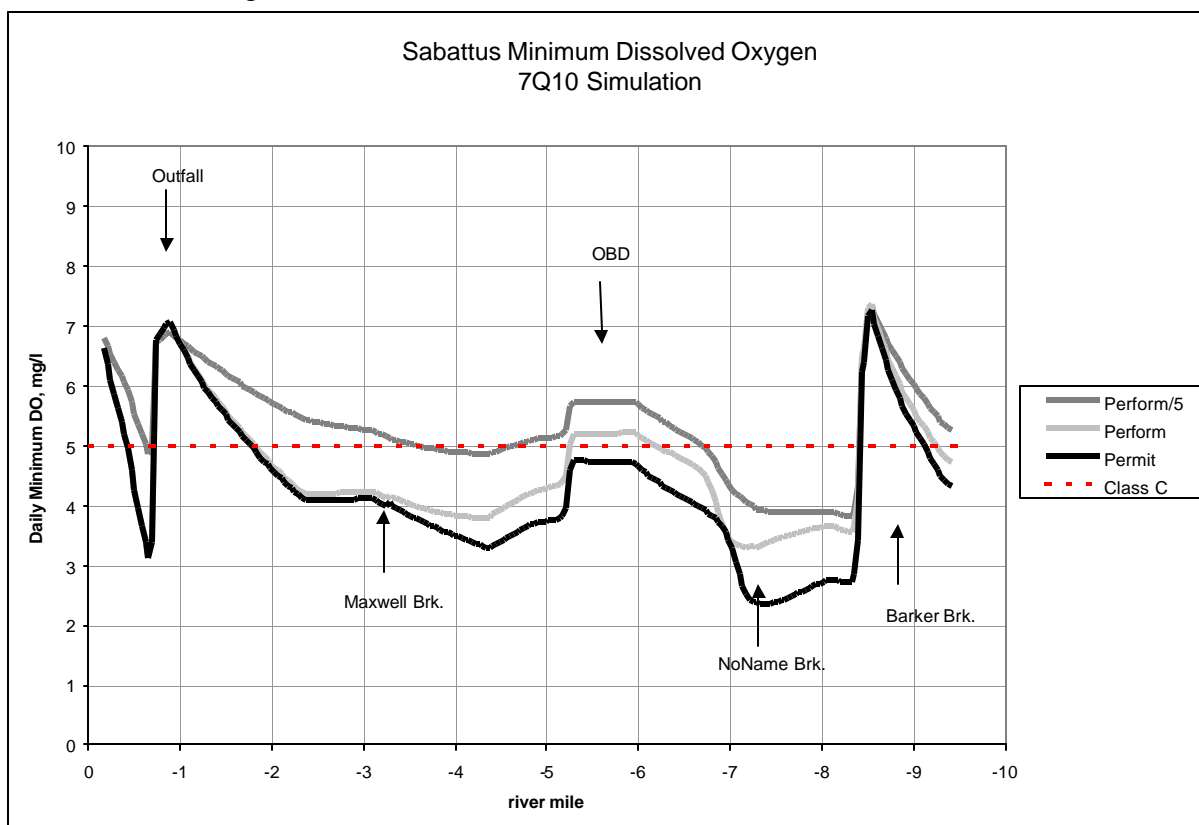
Performance point loads (from 5 years discharge data) decrease non attainment miles by 15% and zero discharges decrease non attainment by a similar amount although chl-a is significantly reduced over the performance condition.

A scenario was run that assumed a combination of performance point loads and increased 7Q10 flow to 5 cfs. This resulted in a decrease in non attainment of 61%.

An algae bloom is defined as a chl-a concentration of 8-12 ug/l and greater. River miles exhibiting bloom conditions for each scenario are shown in table 10. Point sources are the major factor relating to algae bloom occurrence.

The following chart shows a comparison of resulting minimum DO for selected scenarios (permit load, performance load and performance load with 5 cfs river flow):

Figure 21 Minimum DO for Selected Critical Flow Scenarios

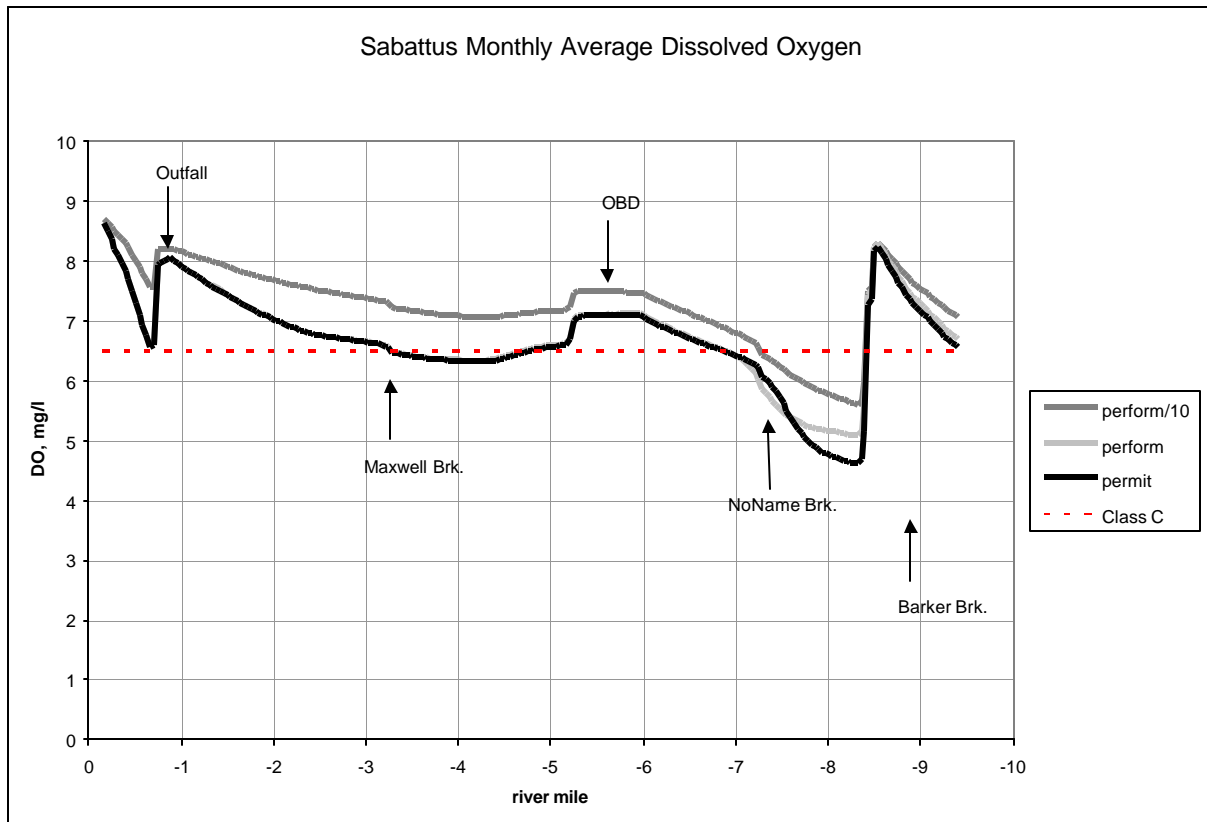


30Q10 Runs

These runs resulted in an anomaly in that the performance and license load runs resulted in fewer non attainment miles (32% reduction) than the zero discharge run, although the zero discharge run resulted in decreased chl-a concentration. This is due to the fact that for the 30Q10 evaluation only daily average DO (not daily minimum) is considered and that chl-a concentrations can result in a gain in DO over the course of a day (produce more DO during daylight than is consumed at night).

The following chart shows the average daily DO for the 30Q10 scenarios (permit load, performance load and performance load with 10 cfs river flow):

Figure 22 DO for Monthly Average Scenarios



Discussion

Historic organic loading along with the hydraulic alteration due to dams is the major contributor to DO depletion in Sabattus River. DO sags occur in each of the impounded segments of the river including a naturally impounded segment above the falls at Crowley Road. Within these impoundments organic loading settles out of the water column resulting in SOD and subsequent recycling of nutrients and BOD from the sediments to the water column. This coupled with the long travel time results in significant DO depletion.

SOD was not measured during the Sabattus River surveys but the modeled values are within the range of measurements made in other Maine rivers. The maximum SOD rate chosen for the Sabattus River is low compared to measured maximum values. Therefore it is reasonable to conclude that the model does not overstate the impact of SOD. Depressed DO readings measured near the bottom of the river impoundments during the surveys also indicate a significant SOD.

Nutrient loading from the point sources is shown to have a significant impact upon algae growth. Under 7Q10 low flow conditions and permit loading, 63% of the river would be expected to experience algae bloom conditions (chl-a \Rightarrow 8 ug/l). Under 30Q10 (monthly average) low flow conditions 100% of the river would experience algae bloom conditions, the difference being increased river flow providing increased chl-a and nutrient loading from the pond. Under zero discharge scenarios blooms are reduced

to approximately 28% of the river study segment. There are currently no numeric algae bloom standards for rivers but nutrient criteria standards are under development and expected to be implemented by 2005.

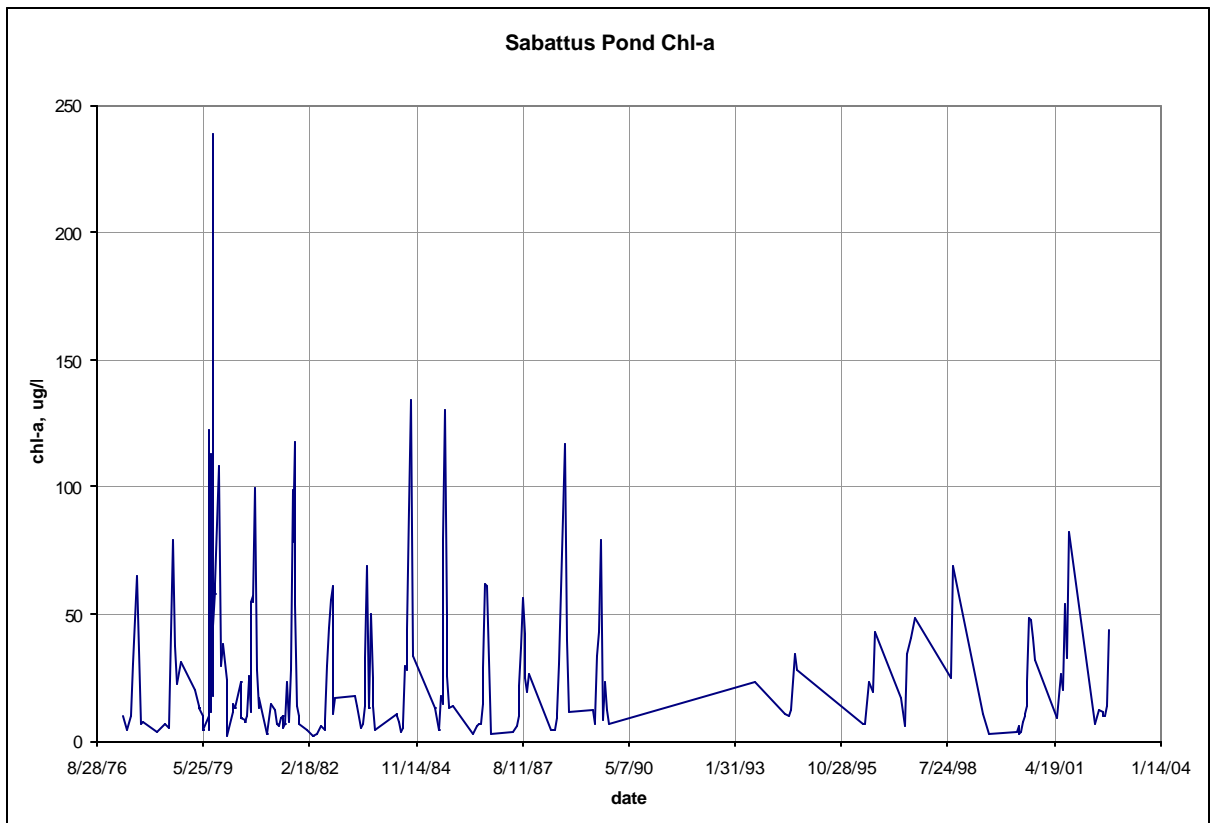
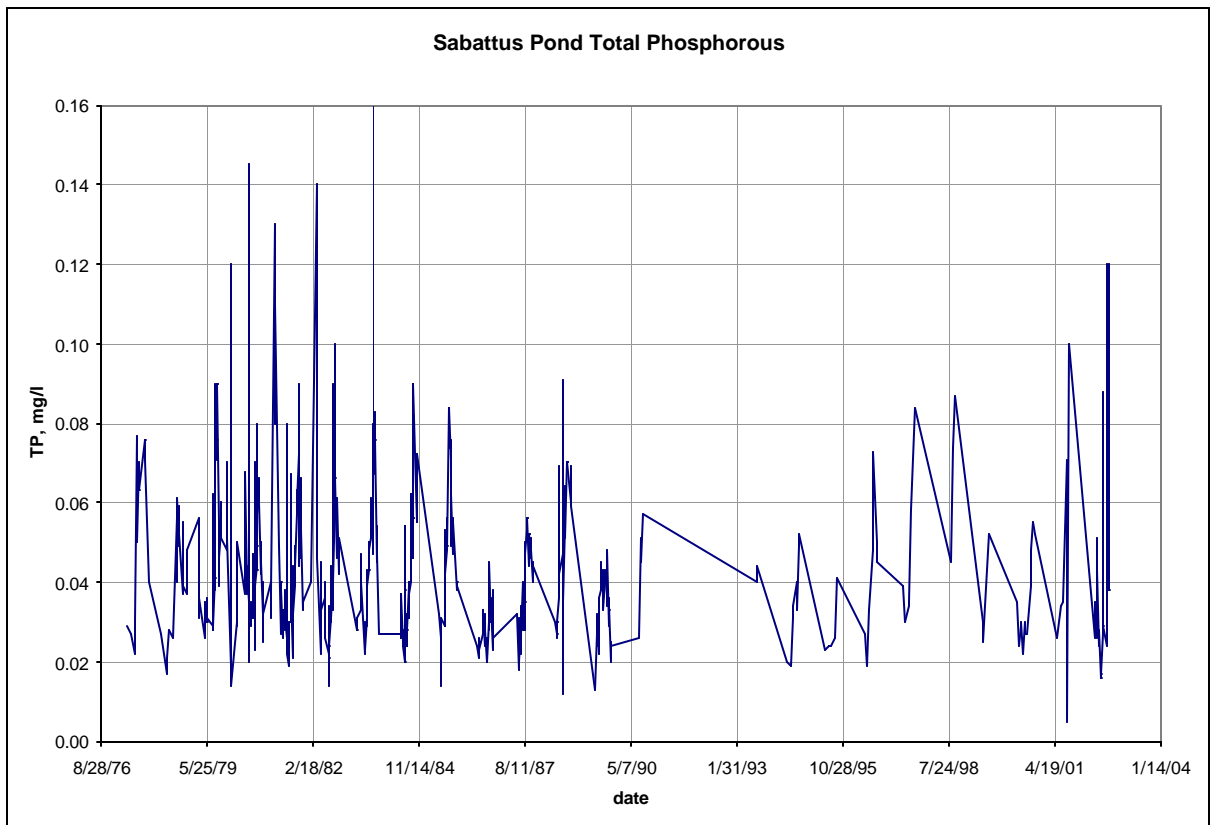
River flow was shown to have a significant impact upon river DO. A flow of 2.5 cfs was assumed for critical conditions because it is the designated minimum flow at the outlet of Sabattus Pond. Flow measured during the 2002 survey (middle of an extended drought) was closer to 5 cfs. This raises the question as to whether the minimum flow is realistic.

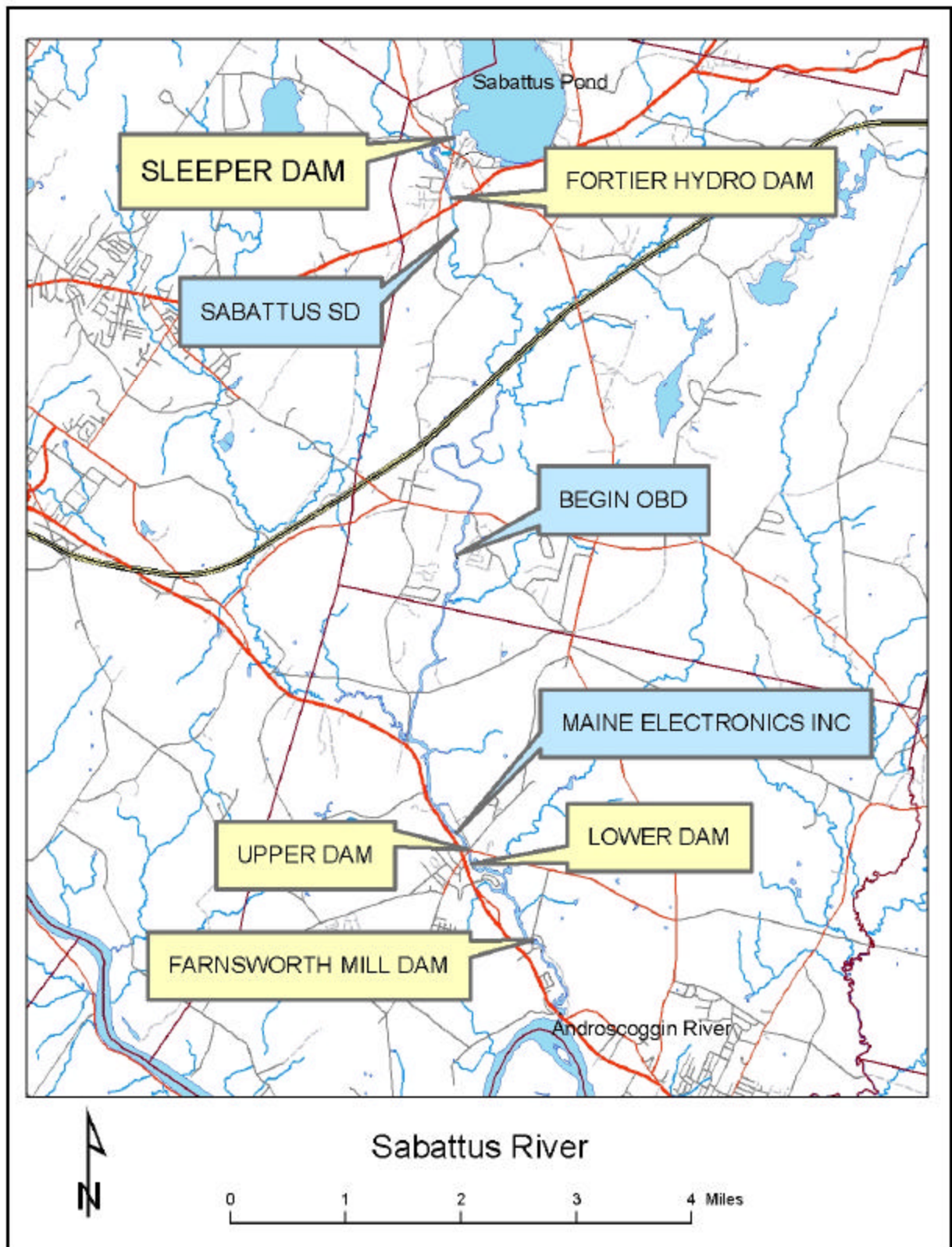
Historically, Sabattus Pond has experienced significant algae blooms, ultimately resulting in high organic loading to the river. It could be reasonably assumed that with improvement in pond water quality (a lake TMDL is in progress) loading to the river would be reduced and that over time benthic organic matter would be reduced through continued oxidation as well as flushing (mainly during spring flows).

Elimination of the point sources alone would not result in attainment of DO standards although algae blooms would be significantly reduced. Reduced point source loading in combination with a higher designated minimum flow from the pond outlet would eliminate most non attainment river miles, the exception being within the Lisbon Upper Dam impoundment. Full attainment could be achieved only with reduction of SOD or removal of the dam.

This modeling report will become part of a TMDL for the Sabattus River.

APPENDIX



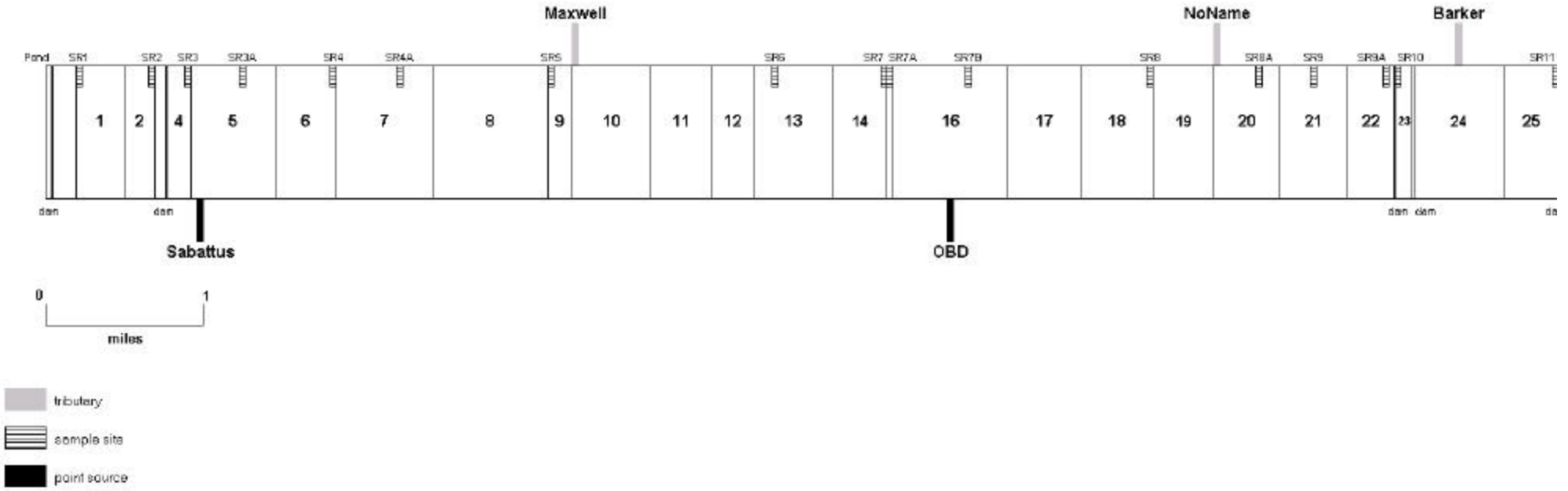


Sabattus Sanitary District Permit

Effluent Characteristic	Discharge Limitations						Monitoring Requirements	
	Monthly Average	Weekly Average	Daily Maximum	Monthly Average	Weekly Average	Daily Maximum	Measurement Frequency	Sample Type
	lb/day	lb/day	lb/day	as specified	as specified	as specified	as specified	as specified
Flow [50050]	---	---	---	0.12 mgd [03]	---	---	Continuous [CN]	Recorder [RC]
BOD ₅ [00310]	17 [26]	45 [26]	50 [26]	17 mg/L [19]	45 mg/L [19]	50 mg/L [19]	1/Week [01/07]	24-Hr. Composite [24]
BOD Percent Removal ⁽¹⁾ [81010]	---	---	---	85% [23]	---	---	1/Month [01/30]	Calculate [CA]
TSS [00530]	30 [26]	45 [26]	50 [26]	30 mg/L [19]	45 mg/L [19]	50 mg/L [19]	1/Week [01/07]	24-Hr. Composite [24]
TSS Percent Removal ⁽¹⁾ [81011]	---	---	---	85% [23]	---	---	1/Month [01/30]	Calculate [CA]
Settleable Solids [00545]	---	---	---	---	---	0.3 ml/L [25]	1/Day [01/01]	Grab [GR]
E. coli Bacteria ⁽²⁾ (May 15 – September 30) [31633]	---	---	---	142/100 ml ⁽³⁾ [13]	---	949/100 ml [13]	1/Week [01/07]	Grab [GR]
Total Residual Chlorine ⁽²⁾ (May 15 – September 30) [50060]	---	---	---	0.1 mg/L [19]	---	0.27 mg/L [19]	1/Day [01/01]	Grab [GR]
Total Phosphorous ⁽⁴⁾ [00665]	Report lb/day [26]	---	---	Report mg/L [19]	---	---	1/Week [01/07]	24-Hr. Composite [24]
pH [00400]	---	---	---	---	---	6.0-9.0 S.U. [12]	1/Day [01/01]	Grab [GR]

Gerard Begin OBD Permit

Effluent Characteristic	Discharge Limitations		Monitoring Requirements	
	Monthly Average	Daily Maximum	Measurement Frequency	Sample Type
Flow		20,000	Monthly	Estimate
Biochemical Oxygen Demand	30 mg/L	50 mg/L	Monthly	Grab
Total Suspended Solids	30 mg/L	50 mg/L	Monthly	Grab
Settleable Solids	Report Only	Report Only	Monthly	Grab
Eschericia coli Bacteria ¹	64 col/100ml	427 col/100ml	Monthly	Grab
Total Residual Chlorine ¹		1.0 mg/L	Weekdays	Grab
The pH shall not be less than 6.0 or greater than 8.5 at any time.				



Model Segmentation